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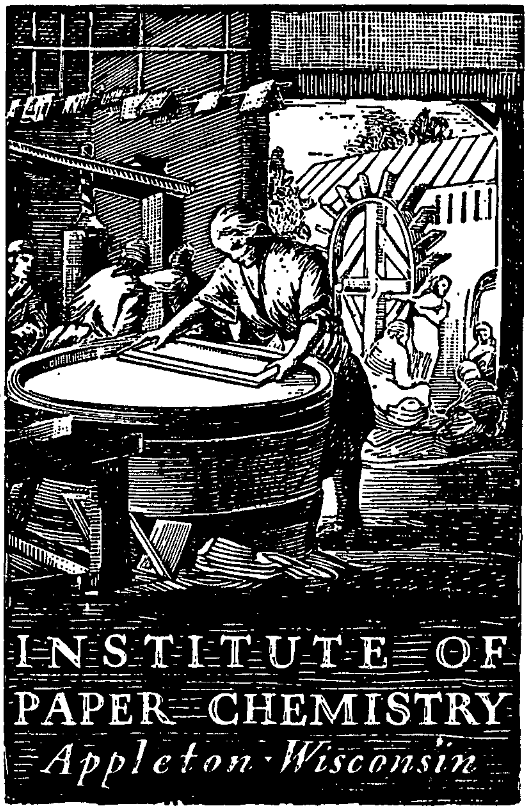

COMPARATIVE EVALUATION OF B- AND C-FLUTE BOXES AND COMBINED BOARD FABRICATED WITH VARIOUS CORRUGATING MEDIUM WEIGHTS

Project 2695-18

Report One

A Progress Report

to

FOURDRINIER KRAFT BOARD INSTITUTE, INC.

February 9, 1976

GENERAL

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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TABLE OF CONTENTS

	Page
SUMMARY	1
INTRODUCTION	5
MATERIALS AND FABRICATION	7
TEST PROCEDURES	10
Conditioning	10
Boxes	10
Combined Board	10
Components	10
DISCUSSION OF RESULTS	13
Box Performance	13
Combined Board Results	27
Component Test Results	41
LITERATURE CITED	45
APPENDIX I. BOX DEFLECTION RESULTS	46
APPENDIX II. COMBINED BOARD TEST RESULTS	48

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

COMPARATIVE EVALUATION OF B- AND C-FLUTE BOXES AND COMBINED BOARD FABRICATED WITH VARIOUS CORRUGATING MEDIUM WEIGHTS

SUMMARY

The Rule 41 requirement, specifying that the minimum caliper and basis weight of the corrugating medium should be 0.009 inch and 26 lb, respectively, was established many years ago. Because of the significant improvements in medium quality since the Rule 41 specifications were established, it appeared that it may be possible to make boxes at lower medium weight which would give adequate performance. Accordingly, a study was initiated to comparatively evaluate the performance of combined board and boxes fabricated with 21-, 23- and 26-lb corrugating medium, each fabricated with 26-, 42- and 90-lb linerboard.

While it was not possible to obtain mediums having the desired weights and Concora strengths from a single machine, four mediums were supplied made by different companies as follows:

Medium No.	Basis Weight, lb/M ft^2	Concora, lb
1	26.2	67
2	23.3	54
4	21.7	44
3	20.0	41

As a matter of convenience in the discussion, the mediums are referred to as 26-, 23-, 22- and 20-lb in the same order as listed above.

The above mediums were fabricated into B- and C-flute combined boards and boxes. In the case of the C-flute combinations, each medium was combined with

26-, 42- and 90-lb liners. For the B-flute combinations, each medium was combined with 42-lb liners. Two box sizes were made for each combination: No. 2-1/2 can size and 22 x 16 x 18-inch size.

The following results were obtained:

1. GENERAL.

The boxes and combined boards made with the 23-lb medium generally exhibited performances which were about equal to or slightly lower than the performances of the constructions made with 26-lb medium. Thus reductions in Rule 41 corrugating medium weight and caliper requirements may be feasible in order to bring about savings in fiber and capital requirements. A detailed summary of the results is given below.

2. BOX PERFORMANCE.

a. Top-load box compression.

On an overall basis the 23-, 22- and 20-lb medium constructions exhibited percentage reductions in strength of -2.5, -12.8 and -18.4%, respectively. Thus the top-load compression strengths of the boxes made with 23-lb mediums were essentially the same as for the boxes made with 26-lb medium.

b. End-load compression.

The overall average results show that the boxes made with 23-, 22- and 20-lb medium exhibited reductions in strength of -6.9, -15.3 and -21.2%, respectively. Thus the 23-lb constructions exhibited only modestly lower end-load box strengths as compared to the 26-lb medium constructions.

c. Twelve-inch corner drop.

The average results show that the 23-, 22- and 20-lb mediums exhibited reductions in drop performance of -29.8, -9.5 and -21.4%, respectively. These differences in performance appeared to be very much dependent on the tearing strengths of the mediums. For example, the tearing strength of the 22-lb medium was about the same as for the 26-lb medium and the difference in drop test results (-9.5%) was not statistically significant. On the other hand, both the 23- and 20-lb mediums were made with relatively low tearing strength compared to the 26-lb medium and both exhibited low drop test performances. Thus the differences in drop test performance appeared to be more affected by tearing strength than medium weight.

3. COMBINED BOARD PERFORMANCE.

The overall average percentage changes in combined board properties of the combined boards made with 23-, 22- and 20-lb mediums are listed below.

Combined Board Property	Percent Change Relative to 26-lb Medium Constructions		
	23-lb Medium Comb. Bd.	22-lb Medium Comb. Bd.	20-lb Medium Comb. Bd.
Caliper	-1.3	-4.0	-7.3
Bursting strength	+0.3	-1.8	-3.3
Flat crush	+1.4	-37.9	-39.6
Edgewise compression			
MD	+3.0	-9.8	-6.9
CD	+2.8	-8.7	-9.4
Flexural stiffness			
MD (D_x)	-5.1	-5.7	-15.7
CD (D_y)	-7.1	-7.1	-15.0
$\sqrt{D_x D_y}$	-6.3	-6.6	-15.9

a. The combined boards made with 23-, 22- and 20-lb mediums exhibited about the same bursting strength as the boards made with 26-lb medium. This would be expected.

b. It may be noted that the properties of the 23-lb medium constructions were about the same as for the 26-lb constructions although the flexural stiffnesses were modestly lower.

c. The 22- and 20-lb medium constructions exhibited lower performances in all cases than the 26-lb medium constructions. This was particularly evident in the case of the flat crush and, to a lesser extent, for caliper, edgewise compression and flexural stiffness.

4. MEDIUM CHARACTERISTICS

a. The 23-lb medium supplied for the study exhibited lower Concora, caliper and tearing strength than the 26-lb medium but its modified ring strength was about equal to that of the 26-lb medium.

b. The 22- and 20-lb mediums exhibited markedly lower Concora, caliper and modified ring compression strength. With regard to tearing strength, the 22-lb medium was about equal to the 26-lb while the 20-lb medium exhibited much lower tearing strengths than the 26-lb medium.

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REPORT ONE

22" X16" X18" box

$a = \frac{(TL)(COS)}{2(H-t)}$

$b = \frac{(TL)(COS)}{2H}$

	in MD						ac MD					
	BU SF Side in Comp		BD DF Side in Comp		AV ✓		BU		BD		AV	
Code	a	b	a	b	a	b	a	b	a	b	a	b
C813	5.74	5.44	6.67	6.31	6.20	5.88	18.72	17.72	19.89	18.82	19.30	18.27
C814	6.67	6.32	7.40	6.99	7.04	6.66	24.11	22.67	24.82	23.34	24.46	23.00
C815	6.18	5.81	6.15	5.78	6.16	5.80	16.78	15.78	17.98	16.90	17.38	16.34
C816	6.25	5.89	6.58	6.30	6.42	6.10	19.43	18.32	16.19	15.27	17.81	16.80
C817	14.13	13.01	13.26	12.28	13.70	12.64	17.28	16.01	21.90	20.28	19.59	18.14
C818	13.34	12.35	13.68	12.65	13.51	12.50	23.44	21.68	23.00	21.28	23.22	21.48
C819	13.85	12.86	14.37	13.34	14.11	13.10	24.81	23.04	24.86	23.08	24.84	23.06
C820	14.48	13.45	14.69	13.64	14.58	13.54	25.26	23.47	22.97	21.34	24.12	22.40
C821	37.55	32.70	37.16	33.56	37.36	33.13	47.76	41.59	41.95	36.53	44.86	39.06
C822	29.90	25.99	33.43	29.06	31.66	27.52	54.71	47.56	46.52	40.44	50.62	44.00
C823	25.25	21.73	26.09	22.45	25.67	22.09	48.48	41.73	43.63	37.54	46.06	39.64
C824	26.39	22.94	25.89	22.50	26.14	22.72	47.86	41.69	39.58	34.70	43.72	38.34
C825	18.25	16.54	18.54	16.79	18.40	16.66	25.54	23.14	26.32	23.85	25.93	23.50
C826	16.98	15.38	18.82	17.05	17.90	16.22	26.18	23.72	25.26	22.88	25.72	23.30
C827	17.48	15.79	17.62	15.92	17.55	15.86	25.56	23.09	23.08	20.86	24.32	21.97
C828	17.84	16.49	17.40	16.28	17.62	16.54	27.81	25.19	22.08	20.00	24.94	22.60

INTRODUCTION

The Rule 41 requirement, specifying that the minimum caliper and basis weight of corrugating medium should be 0.009 inch and 26 lb, respectively, was established many years ago when the principal mediums were straw and chestnut. The quality level at the time these specifications were established was considerably lower than the quality of current corrugating mediums. It also may be noted that in many European countries the standard corrugating medium weight is no more than 23 lb/M ft^2.

Because of the very significant improvement in medium quality since the establishment of the corrugating medium specifications in Rule 41, it appears that it should be possible to make boxes at a lower medium weight which will perform satisfactorily. This would bring about savings in fiber and capital requirements.

Accordingly, a study was initiated to comparatively evaluate the performance of combined board and boxes fabricated with 21-, 23- and 26-lb corrugating medium, each fabricated with 26-, 42- and 90-lb linerboard.

Before undertaking the study, the Technical Division of FKI requested that a literature survey be performed to determine if a similar study had been carried out and reported in the literature. The survey findings were summarized in a report to the Technical Division dated Feb. 28, 1975 (1). The survey uncovered no study of the type proposed and the Institute was authorized at the Technical Division meeting on March 18 and 19, 1975 to undertake the experimental phase.

At the time the experimental phase was initiated, it was decided that the evaluation program should be enlarged to include (a) the effect of rough-handling pretreatment on box performance, and (b) torsion tear tests on combined board. Inasmuch as funds were not available to cover the costs of the additional work in the 1975 budget, it was decided to defer the rough-handling pretreatment until 1976. However, it was requested that sufficient boxes be made during the fabrication program to carry out the additional box performance evaluation in 1976.

MATERIALS AND FABRICATION

It was initially proposed that all the experimental mediums be made on one machine at the following CMT levels:

1. 26-lb medium — 70-lb Concora
2. 23-lb medium — 70-lb Concora
3. 23-lb medium — 62-lb Concora
4. 21-lb medium — 70-lb Concora
5. 21-lb medium — 56-lb Concora

However, it was impossible to obtain the mediums from one machine and it was also impossible to obtain all the mediums at the desired Concora levels. As a result, only four mediums were made available for this study as shown in Table I. Each medium was supplied by a different mill.

TABLE I

CHARACTERISTICS OF CORRUGATING MEDIUMS SUPPLIED FOR THE STUDY

Corrugating Medium No.	Basis Weight, lb/M ft^2 Nominal Level	Basis Weight, lb/M ft^2 Av. Test Level	Concora, lb
1	26	26.2	67
2	23	23.3	54
4[a]	21[a]	21.7	44
3[a]	21[a]	20.0	41

[a]As a matter of convenience in the text, No. 3 is referred to as 20-lb and No. 4 as 22-lb medium.

The 26-, 42- and 90-lb unbleached kraft linerboards required for the study were supplied by one of the FKI member mills.

The above materials were fabricated into combined board and boxes at the Hi-way 41 plant of Menasha Corporation. The run identifications are shown in Table II. The runs were carried out in the sequence shown except that Runs 2, 4 and 5 had to be rerun because of poor adhesion. Run 4 was made four times before acceptable adhesion was obtained. These reruns were made after all other runs had been carried out. Satisfactory adhesion was obtained by increasing the opening at the single-facer from 0.0085 to eventually 0.0105. The opening at the double-backer was 0.010. The Stein-Hall viscosity of the single-face adhesive was approximately 23 seconds; the viscosity of the double-backer adhesive was 32 seconds.

TABLE II

RUN IDENTIFICATION AND SEQUENCE

Run No.	Flute	Liner Weight	Corrugating Medium Nominal Weight	Corrugating Medium Sample No.
1	C	26	26	1
2	C	26	23	2
3	C	26	21	3
4	C	26	21	4
5	C	42	21	4
6	C	42	21	3
7	C	42	23	2
8	C	42	26	1
9	C	90	26	1
10	C	90	23	2
11	C	90	21	3
12	C	90	21	4
13	B	42	26	1
14	B	42	23	2
15	B	42	21	3
16	B	42	21	4

The speed during the runs was maintained at between 350-400 fpm.

Two size blanks were cut on the corrugator. The 24 No. 2-1/2 can size blanks were made on the front side and 22 x 16 x 18-inch size boxes on the back side. Both size boxes were made with a glued manufacturers joint (glue lap attached to side panel and adhered to end panel).

The medium rolls were sampled before and after each run whereas the liner rolls were sampled at the start and end of each roll.

The 24 No. 2-1/2 can size boxes were printed, slotted, scored, etc., on an S & S flexo-folder-gluer. The 22 x 16 x 18-inch size boxes were run on a Hooper-Swift flexo-folder-gluer. Considerable difficulty was encountered on the flexo-folder-gluers with pull roll crushing, especially with the boxes made with 20- and 22-lb mediums at the Concora levels supplied.

TEST PROCEDURES

CONDITIONING

All samples (component, combined boards and boxes) were preconditioned for 24 hours at less than 35% RH and 23°C. They were then conditioned for at least 48 hours at 50% ± 2% RH and 23 ± 1.0°C prior to evaluation.

BOXES

The experimental boxes were evaluated in terms of the following tests:

1. Top-load box compression: 10 box tests for each size box.
2. End-load box compression: 10 box tests for each size box.
3. Twelve-inch corner drop with water-filled cans as contents — 5 box tests, No. 2-1/2 can boxes only.

COMBINED BOARD

The combined board tests were made on material cut from the No. 2-1/2 can size and 22 x 16 x 18-inch size boxes as listed in Table III.

COMPONENTS

The tests carried out on the components are listed in Table IV.

TABLE III

COMBINED BOARD TESTS

Test	Test Method	Number of Determinations: Combined Boards from Large Boxes	Combined Boards from Small Boxes	Total
Basis weight	T410	1000 ft^2	1000 ft^2	--
Caliper	T411	10	10	20
Bursting strength	T810	10 (5 up, 5 down)	10 (5 up, 5 down)	20
Flat crush	T808	10	10	20
Pin adhesion	RC337	6	6	12
Edgewise compression				
MD	T811[a]	10	10	20
CD	T811	10	10	20
Flexural stiffness				
MD	Institute[b]	10 (5 up, 5 down)	10 (5 up, 5 down)	20
CD	Institute[b]	10 (5 up, 5 down)	10 (5 up, 5 down)	20

[a]These MD tests were carried out using essentially the same procedures as specified in T811 for CD tests. The specimen dimensions were as follows: 2 inches wide x 4.5 flutes long in the MD. The edges to be loaded during test were reinforced with Carbowax 4000 wax.

[b]The 4-point beam tests were carried out using the following specimen dimensions:

	MD	CD
Center span	6	5.83
Overhang span	3	1.45
Total span	12	8.73

Load spreaders were used for the MD tests and in some cases for the CD tests.

TABLE IV

COMPONENT TESTS

Test	Number of Determinations: Linerboard	Number of Determinations: Corrugating Medium
Basis weight	1000 ft^2	1000 ft^2
Caliper	20	20
Bursting strength	20	--
Edgewise compression		
MD	20	20
CD	20	20
Concora	--	20
Elmendorf tearing strength		
MD	6	6
CD	6	6

DISCUSSION OF RESULTS

BOX PERFORMANCE

As mentioned previously, four corrugating mediums ranging in basis weight from 20.0 to 26.2 lb/M ft^2 were fabricated into B- and C-flute combined boards and boxes. In the case of the C-flute combinations, each medium was combined with 26-, 42- and 90-lb liners. For the B-flute combinations, each medium was combined with 42-lb liners. Two box sizes were made for each combination; namely, No. 2-1/2 can size and 22 x 16 x 18-inch size.

The top-load box compression results are summarized in Table V and illustrated in Fig. 1 and 2 for the No. 2-1/2 can and 22 x 16 x 18-inch size boxes, respectively. (Note the top-load deflection results are shown in Appendix I.) It may be noted in the table that the observed basis weights of the medium were 20.0, 21.7, 23.3 and 26.2 lb with corresponding Concora strengths of 41, 44, 54 and 67 lb. For convenience in the discussion, the mediums will be referred to in terms of "nominal" basis weight — i.e., 20, 22, 23 and 26 lb.

The results for the No. 2-1/2 can size boxes in Table V and Fig. 1 show that the boxes made with 23-lb medium exhibited maximum loads which were approximately equal to the loads exhibited by the boxes made with 26-lb medium. For the C-flute combinations the boxes made with 23-lb mediums exhibited percentage differences of +3.1, -1.3 and -1.3% for the runs made with 26-, 42- and 90-lb liners, respectively, and these differences were not statistically significant at the 0.05 level. For the B-flute combination with 42-lb facings the boxes made with 23-lb medium gave a percentage difference of -7.1 which was statistically significant at the 0.05 level. For the composite of the No. 2-1/2 can size results, the boxes made with 23 and 26-lb mediums gave average loads of 808 and 823 lb, and the difference of -1.8% was not statistically significant.

TABLE V

TOP LOAD BOX COMPRESSION RESULTS

	Medium Characteristics		Top Load Compression, lb					
Run	Basis Wt., lb/M ft^2	Concora, lb	No. 2-1/2 Can Box	Diff., %[a]	22x16x18 Inch Box	Diff., %[a]	Composite	Diff., %[a]
			C-flute — 26-lb Liners					
1	26.2	67	446	--	573	--	509	--
2	23.3	54	460	+3.1	603	+5.2	531	+4.3
4	21.7	44	373	-16.4[b]	513	-10.5[b]	443	-13.0[b]
3	20.0	41	363	-18.6[b]	445	-22.3[b]	404	-20.6[b]
			C-flute — 42-lb Liners					
8	26.2	67	685	--	847	--	766	--
7	23.3	54	676	-1.3	817	-3.5	747	-2.5
5	21.7	44	621	-9.3[b]	769	-9.2[b]	695	-9.3[b]
6	20.0	41	580	-15.3[b]	684	-19.2[b]	632	-17.5[b]
			C-flute — 90-lb Liners					
9	26.2	67	1556	--	1874	--	1715	--
10	23.3	54	1535	-1.3	1758	-6.2[b]	1646	-4.0[b]
12	21.7	44	1423	-8.5[b]	1437	-23.3[b]	1430	-16.6[b]
11	20.0	41	1256	-19.3[b]	1440	-23.2[b]	1348	-21.4[b]
			B-flute — 42-lb Liners					
13	26.2	67	605	--	749	--	677	--
14	23.3	54	562	-7.1[b]	738	-1.5	650	-4.0[b]
16	21.7	44	540	-10.7[b]	729	-2.7	634	-6.4[b]
15	20.0	41	544	-10.1[b]	675	-9.9[b]	609	-10.0[b]
			Composite					
--	26.2	67	823	--	1011	--	917	--
--	23.3	54	808	-1.8	979	-3.2[b]	894	-2.5[b]
--	21.7	44	739	-10.2[b]	862	-14.7[b]	800	-12.8[b]
--	20.0	41	686	-16.6[b]	811	-19.8[b]	748	-18.4[b]

[a]Based on results for boxes made with 26-lb medium as reference.

[b]Statistically significant at the 0.05 level.

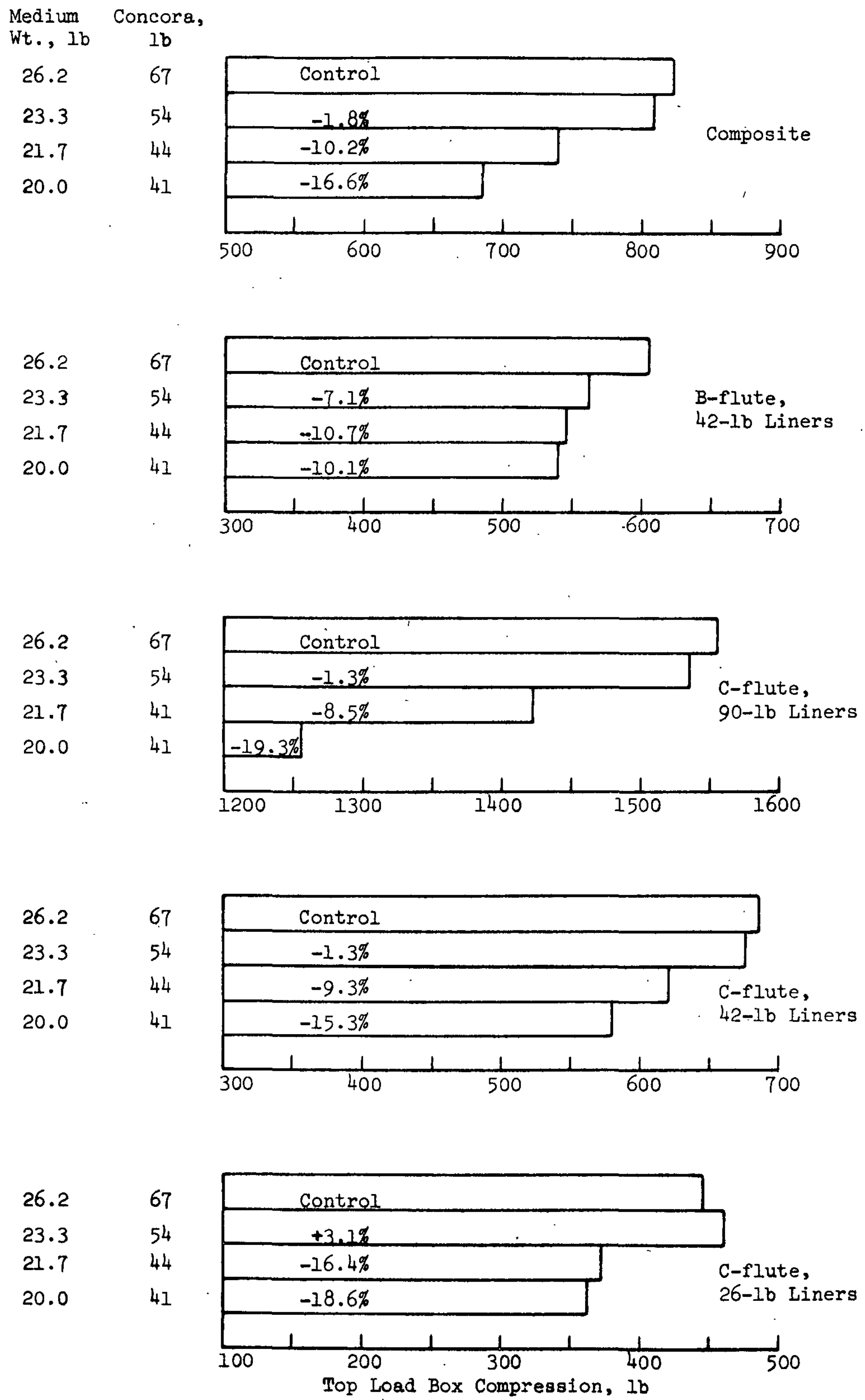

Figure 1. Comparison of Top-load Box Compression Results for No. 2-1/2 Can Size Boxes

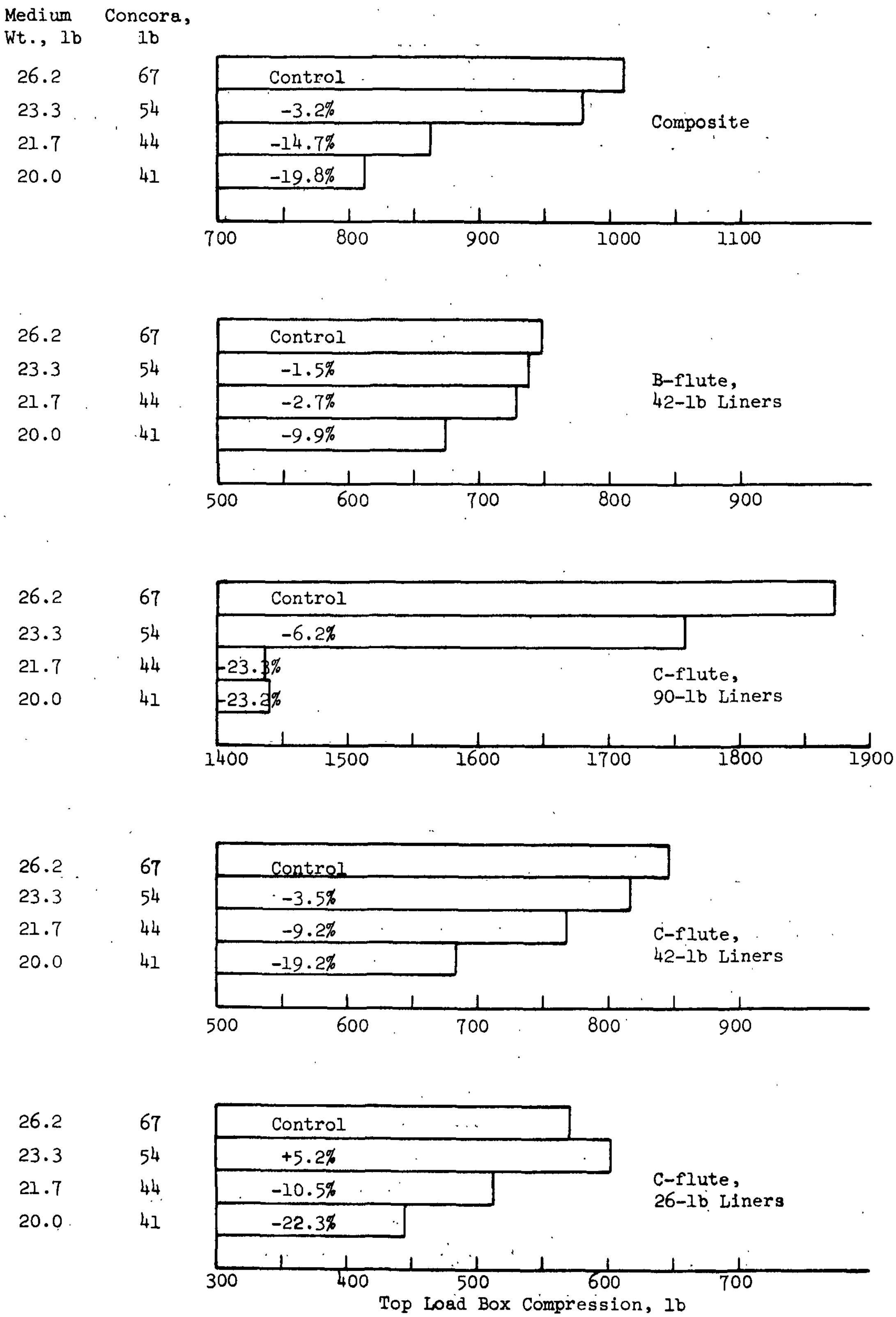

Figure 2. Comparison of Top-load Box Compression Results for the 22 x 16 x 18-Inch Size Boxes

The top-load compression results for the No. 2-1/2 can size boxes made with 20- and 22-lb mediums were significantly lower than the results for the 26-lb medium for all four flute and liner weight combinations. The percentage reductions for the composite No. 2-1/2 can size results were -16.6 and -10.2 for the runs made with 20- and 22-lb mediums, respectively, and both differences were statistically significant.

The top-load compression results for the 22 x 16 x 18-inch size boxes in Table V or Fig. 2 generally showed the same trends as the No. 2-1/2 can size box results. Thus, the boxes made with 23-lb medium exhibited maximum loads which were approximately equal to the loads exhibited by the boxes made with 26-lb medium and a statistically significant difference was obtained for only one of the four flute and facing weight combinations. For the composite of the 22 x 16 x 18-inch size boxes, the boxes made with 23- and 26-lb mediums gave average loads of 979 and 1011 lb for a percentage difference of -3.2%. While this difference was statistically significant, it may not be of practical importance.

The compression results for the 22 x 16 x 18-inch size boxes made with 20- and 22-lb mediums were generally significantly lower than the results for the boxes made with 26-lb medium.

The No. 2-1/2 can size and 22 x 16 x 18-inch top-load box compression results were also composited together for each flute and liner weight combination as shown in Table V and illustrated in Fig. 3. It may be noted that the differences in top-load strength for the combinations made with 23- and 26-lb medium ranged from +4.3% to -4.0% and the grand composite average difference was -2.5%. In three of the five comparisons the percentage differences were statistically significant (even though the differences were relatively small) partly because of the greater number of degrees of freedom associated with each composite average.

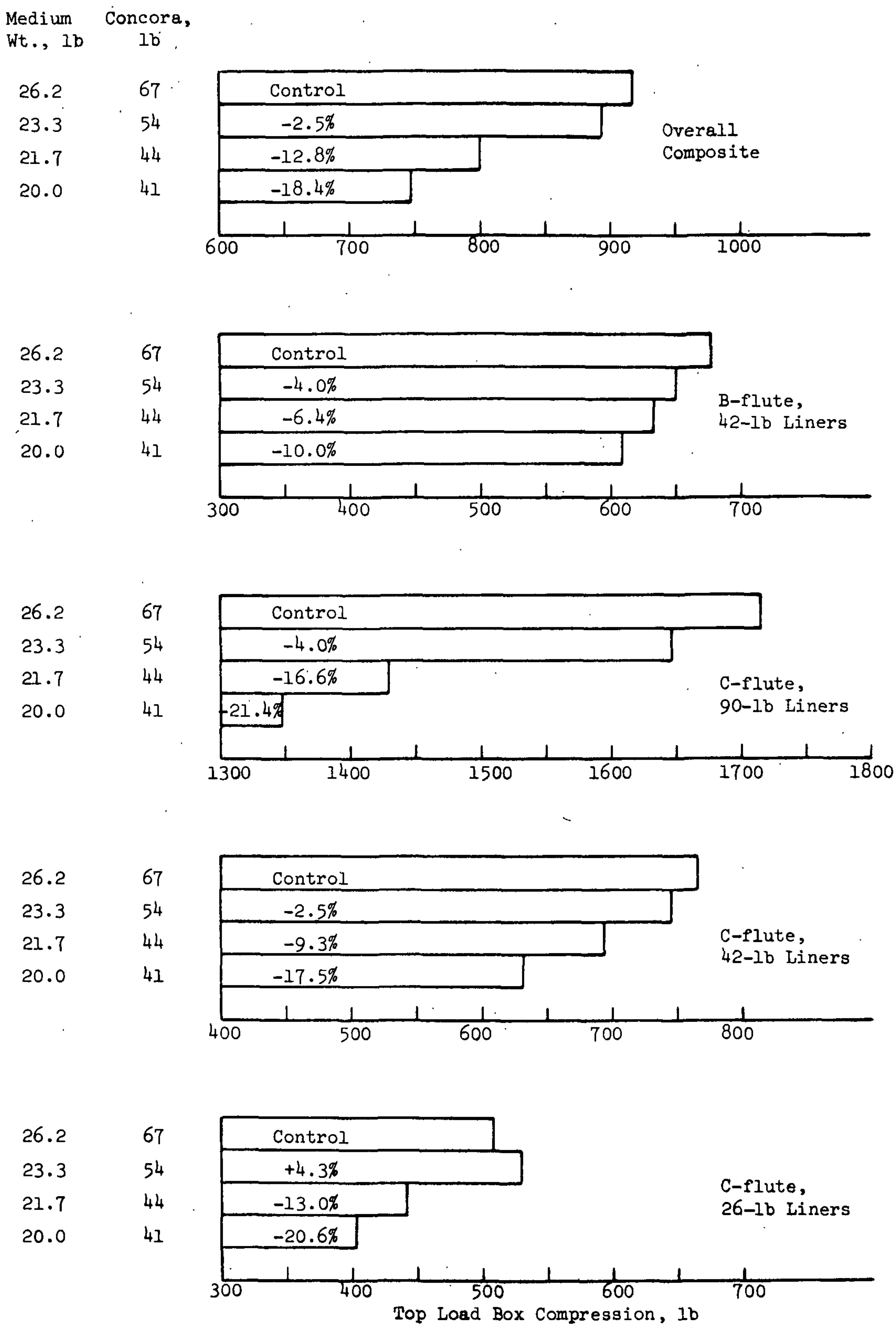

Figure 3. Comparison of Top-load Box Compression Results for the Composite of the No. 2-1/2 Can Size and 22 x 16 x 18-Inch Results

However, because of the small magnitudes of the differences, it appears that the differences in top-load strength between the 23- and 26-lb medium combinations may not be of practical significance. Thus, these results indicate that it may be feasible to consider lowering corrugating medium weight specifications from 26 lb to levels of about 23 lb.

The end-load box compression results are summarized in Table VI and illustrated in Fig. 4 and 5 for the No. 2-1/2 can size and 22 x 16 x 18-inch size boxes, respectively. (Note the end-load box deflection results are shown in Appendix I.) For the No. 2-1/2 can size boxes, the boxes made with 23-lb medium exhibited lower end-load compression strengths than the boxes made with 26-lb medium for three of the four constructions and a higher end-load strength in one case — i.e., for the C-flute boxes with 26-lb liners. On the average, the boxes made with 23-lb medium tested 6.0% lower than the boxes made with 26-lb medium and this difference was statistically significant at the 0.05 level.

The No. 2-1/2 can size boxes made with 20- and 22-lb mediums exhibited lower end-load strengths than the boxes made with 26-lb medium in all four cases and the differences were generally statistically significant. On the average, the reductions in end-load strength for the 20- and 22-lb medium constructions were 26.8 and 16.2%, respectively, and both differences were statistically significant.

The end-load compression results for 22 x 16 x 18-inch size boxes in Table VI and Fig. 5 show that the boxes made with 23-lb medium gave end-load strengths which were not statistically different from the results for the 26-lb medium constructions in three of the four cases — i.e., for the C-flute boxes made with 26- and 42-lb liners and the B-flute boxes with 42-lb liners. For the boxes made with 90-lb liners, the 23-lb medium construction exhibited a

TABLE VI

END LOAD BOX COMPRESSION RESULTS

	Medium Characteristics		End Load Compression, lb					
Run	Basis Wt., lb/M ft²	Concora, lb	No. 2-1/2 Can Box	Diff., %[a]	22x16x18 Inch Box	Diff., %[a]	Composite	Diff., %[a]
			C-flute — 26-lb Facings					
1	26.2	67	267	--	416	--	341	--
2	23.3	54	297	+11.2[b]	399	-4.1	348	+2.1
4	21.7	44	266	-0.4	407	-2.2	336	-1.5
3	20.0	41	230	-13.9[b]	382	-8.2[b]	306	-10.3[b]
			C-flute — 42-lb Facings					
8	26.2	67	589	--	777	--	683	--
7	23.3	54	498	-15.4[b]	784	+0.9	641	-6.1[b]
5	21.7	44	497	-15.6[b]	674	-13.3[b]	586	-14.2[b]
6	20.0	41	405	-31.2[b]	659	-15.2[b]	532	-22.1[b]
			C-flute — 90-lb Facings					
9	26.2	67	1384	--	1555	--	1469	--
10	23.3	54	1304	-5.8[b]	1281	-17.6[b]	1292	-12.0[b]
12	21.7	44	1033	-25.4[b]	1211	-22.1[b]	1122	-23.6[b]
11	20.0	41	917	-33.7[b]	1141	-26.6[b]	1029	-30.0[b]
			B-flute — 42-lb Facings					
13	26.2	67	682	--	859	--	770	--
14	23.3	54	647	-5.1	871	+1.4	759	-1.4
16	21.7	44	652	-4.4	788	-8.3[b]	720	-6.5[b]
15	20.0	41	585	-14.2[b]	826	-3.8	705	-8.4[b]
			Composite					
--	26.2	67	730	--	902	--	816	--
--	23.3	54	686	-6.0[b]	834	-7.5[b]	760	-6.9[b]
--	21.7	44	612	-16.2[b]	770	-14.6[b]	691	-15.3[b]
--	20.0	41	534	-26.8[b]	752	-16.6[b]	643	-21.2[b]

[a] Based on results for combinations made with 26-lb medium as reference.

[b] Statistically significant at the 0.05 level.

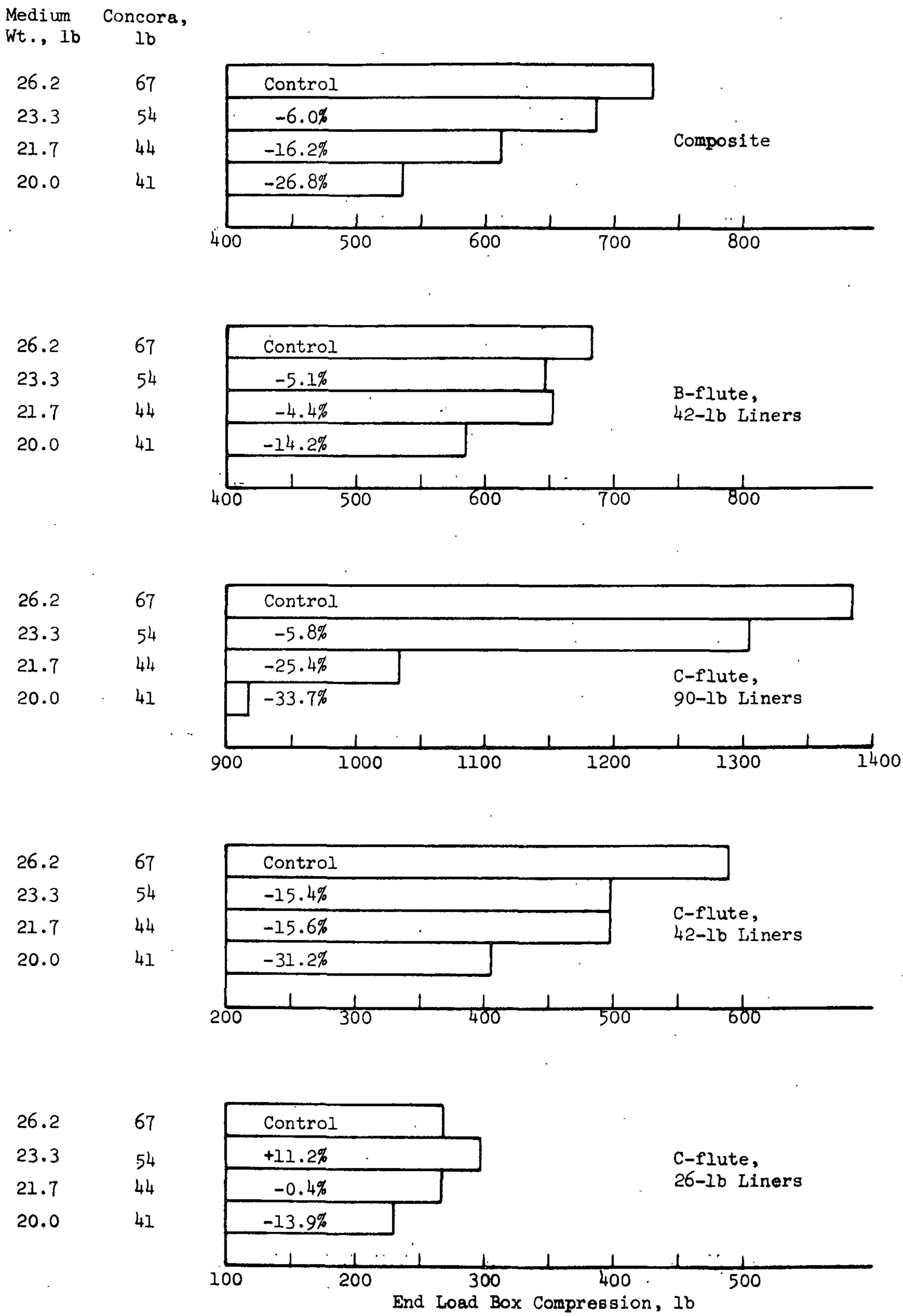

Figure 4. Effect of Medium Weight on the End-load Box Compression Strength of No. 2-1/2 Can Size Boxes

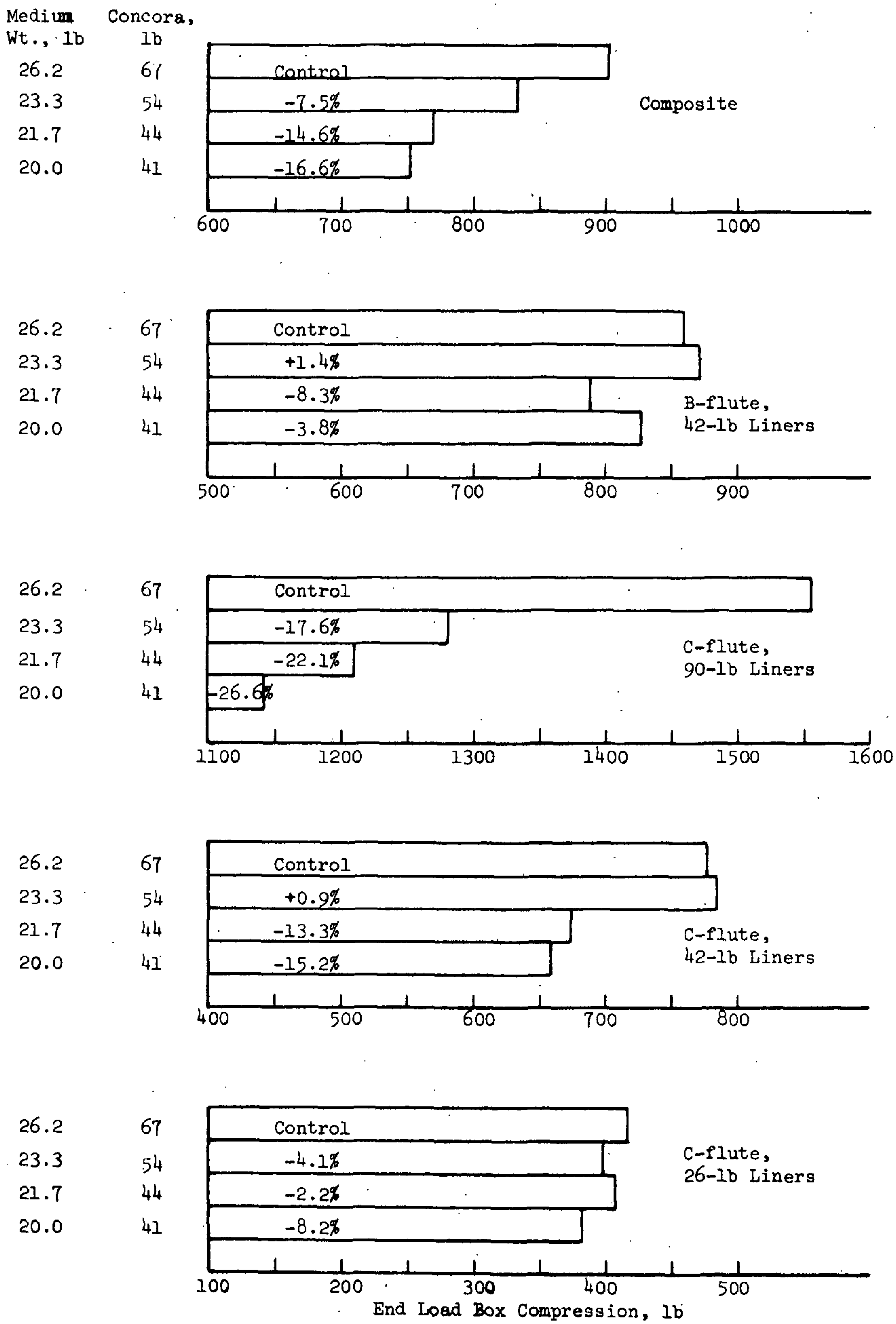

Figure 5. Effect of Medium Weight on the End-load Box Compression Strength of 22 x 16 x 18-Inch Boxes

17.6% reduction in end-load strength relative to the 26-lb medium construction. On the average, the constructions made with 23-lb medium tested 7.5% lower in end-load compression strength for the 22 x 16 x 18-inch boxes — about the same as the corresponding result for the No. 2-1/2 can size boxes. Thus, it appears that boxes made from 23-lb medium exhibit significantly lower end-load compression strengths than boxes made with 26-lb medium in a statistical sense but the reductions in strength are relatively small.

The 22 x 16 x 18-inch boxes made with 20- and 22-lb mediums exhibited lower results than the boxes made with 26-lb medium in all cases and the differences were generally statistically significant. The composite averages for the 22 x 16 x 18-inch boxes show that the 20- and 22-lb medium constructions gave reductions in strength of 16.6 and 14.6%, respectively, and both differences were statistically significant.

The No. 2-1/2 can size and 22 x 16 x 18-inch end-load box compression results were also composited together for each flute and liner weight combination as shown in Table VI and Fig. 6. The grand composite averages show that the constructions made with 23-, 22- and 20-lb mediums exhibited reductions in end-load compression strength of 6.9, 15.3 and 21.2%, respectively, relative to 26-lb medium. Thus, modest decreases in end-load strength were obtained with the 23-lb medium constructions as compared to the 26-lb medium constructions.

The twelve-inch corner drop test results on the No. 2-1/2 can size boxes are tabulated in Table VII and illustrated in Fig. 7. In interpreting the corner drop results, it should be borne in mind that each medium was manufactured by a different company and, hence, there were significant differences in sheet properties other than basis weight and Concora. In particular, the average tearing strengths of the mediums were as follows:

TABLE VII

TWELVE-INCH CORNER DROP TEST RESULTS
ON NO. 2-1/2 CAN SIZE BOXES

Run	Medium Characteristics: Basis Wt., lb/M ft^2	Medium Characteristics: Concora, lb	No. of Drops to Failure	Diff., %[a]
		C-flute — 26-lb Liners		
1	26.2	67	2.6	--
2	23.3	54	2.0	-23.1
4	21.7	44	2.8	+7.7
3	20.0	41	2.4	-7.7
		C-flute — 42-lb Liners		
8	26.2	67	5.8	--
7	23.3	54	3.2	-44.8[b]
5	21.7	44	5.2	-10.3
6	20.0	41	3.4	-41.4[b]
		C-flute — 90-lb Liners		
9	26.2	67	20.0	--
10	23.3	54	15.0	-25.0[b]
12	21.7	44	19.0	-5.0
11	20.0	41	16.8	-16.0[b]
		B-flute — 42-lb Liners		
13	26.2	67	5.0	--
14	23.3	54	3.4	-32.0[b]
16	21.7	44	3.2	-36.0[b]
15	20.0	41	3.6	-28.0[b]
		Composite		
--	26.2	67	8.4	--
--	23.3	54	5.9	-29.8[b]
--	21.7	44	7.6	-9.5
--	20.0	41	6.6	-21.4[b]

[a] Based on results for boxes made with 26-lb medium as reference.

[b] Statistically significant at the 0.05 level.

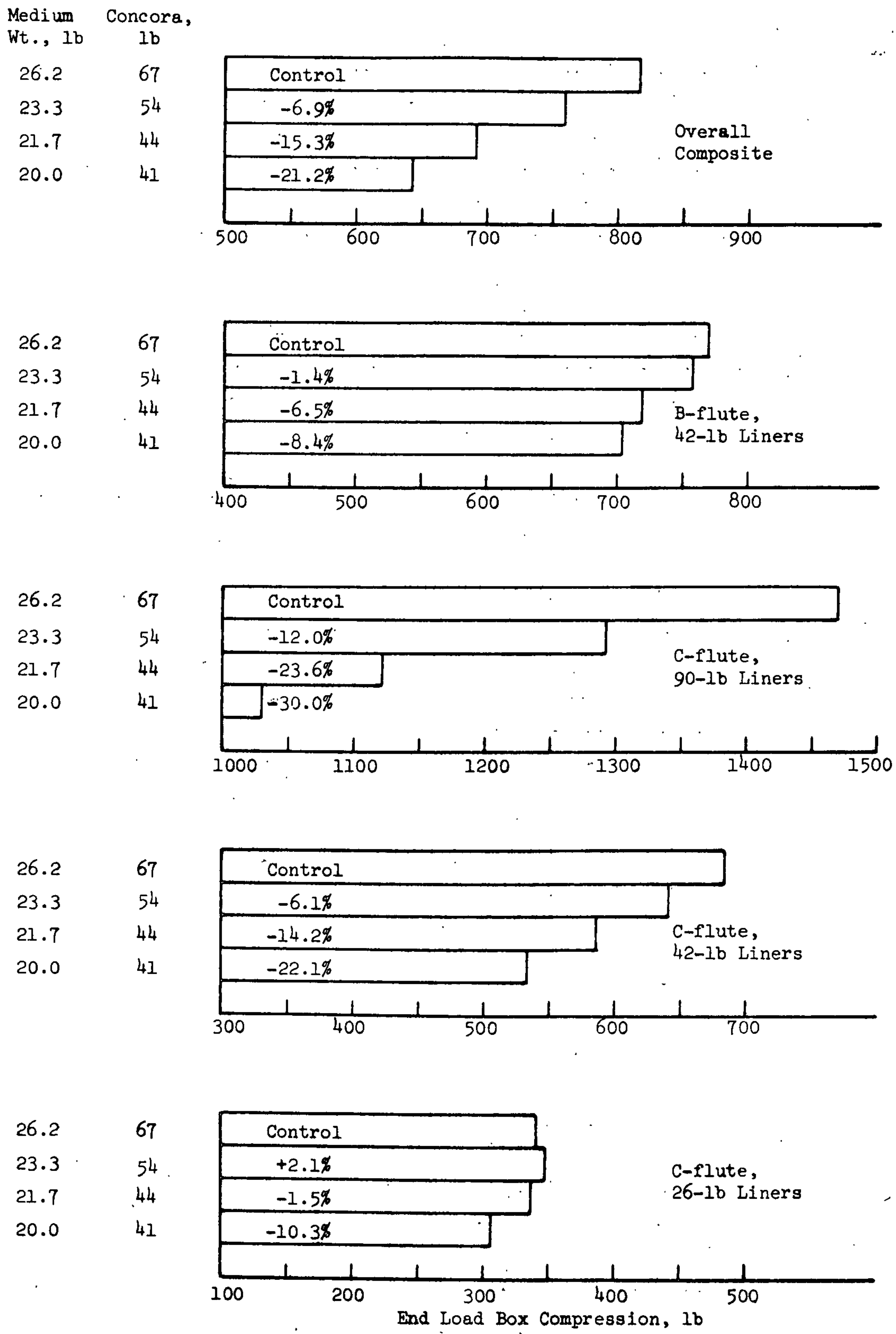

Figure 6. Effect of Medium Weight on the Composite End-load Compression Results for the No. 2-1/2 Can Size and 22 x 16 x 18-Inch Boxes

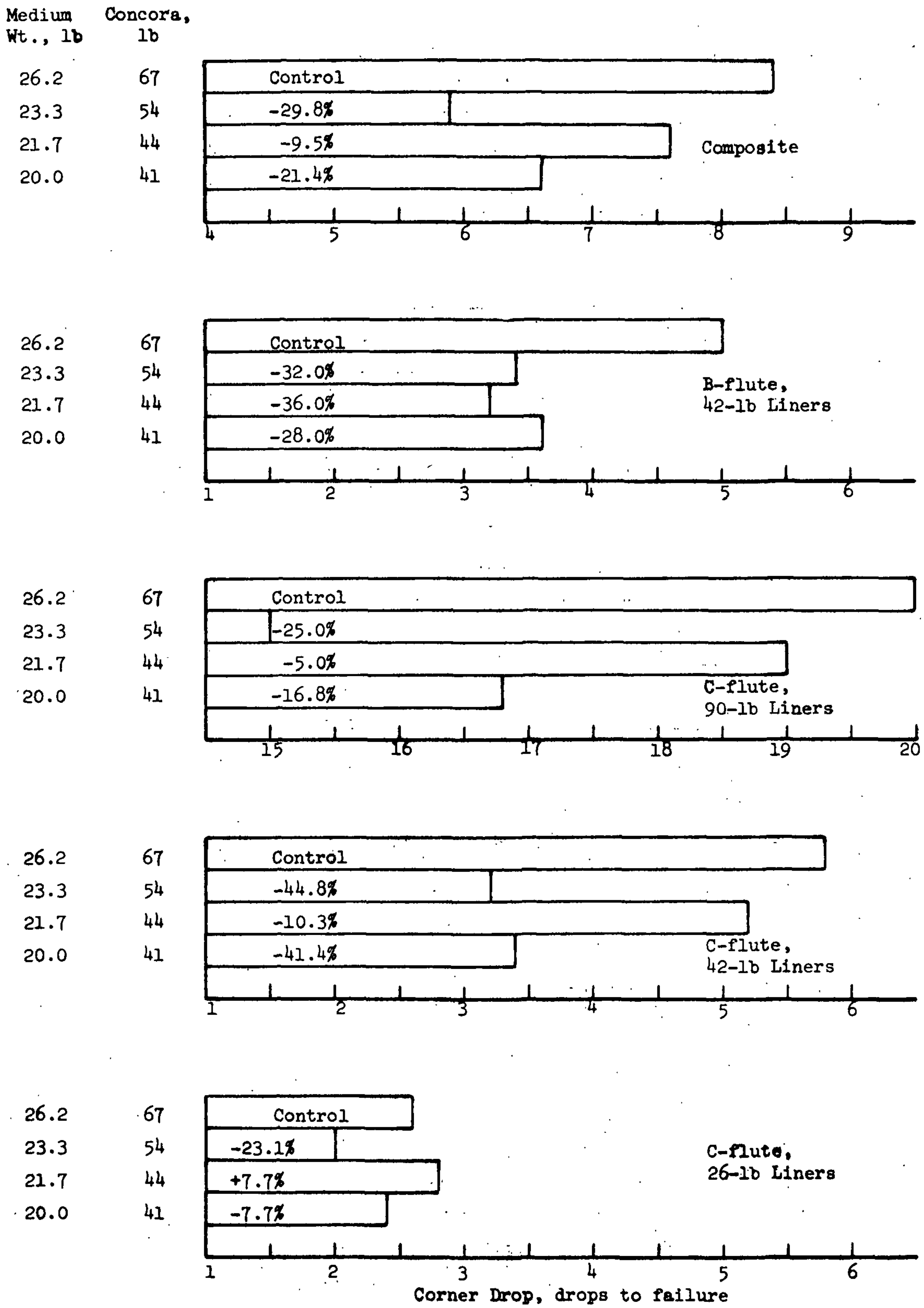

Figure 7. Comparison of Twelve-inch Corner Drop Results for No. 2-1/2 Can Size Boxes

Runs	Basis Wt., lb/M ft^2	Elmendorf Tearing Strength, g MD	CD
1, 8, 9, 13	26.2 (26)	98	128
2, 7, 10, 14	23.3 (23)	53	62
4, 5, 12, 16	21.7 (22)	99	125
3, 6, 11, 15	20.0 (20)	58	70

As may be noted, the 26- and 22-lb mediums exhibited relatively high tearing strengths compared to the 23- and 20-lb mediums. In Table VII and Fig. 7 the corner drop test results tend to parallel the tearing strength characteristics of the mediums. Thus, the 26- and 22-lb box constructions generally exhibited higher drop test results because of their higher tearing strength than the boxes made from the 23- and 20-lb mediums. The drop test results for the 23-lb medium constructions averaged 29.8% lower than for the 26-lb medium constructions but this reduction seems to be primarily due to the difference in tearing strength of the 26- and 23-lb mediums rather than basis weight or Concora.

COMBINED BOARD RESULTS

The average test results obtained on the combined board samples taken from the knockdown boxes of each size are shown in Table VIII. The separate results on samples taken from each box size are shown in Appendix II.

In order to assist in comparing the effect of medium weight on combined board bursting strength, the bursting strength results in Table VIII are retabulated in Table IX and graphically illustrated in Fig. 8. The changes in medium basis weight had little or no effect on the bursting strength of the combined board. This would be expected because combined board bursting strength is primarily dependent

TABLE VIII

COMBINED BOARD TEST RESULTS

Run	Nominal Liner Wt., lb/M ft²	Medium Characteristics: Basis Wt., lb/M ft²	Medium Characteristics: Concora, lb	Basis Wt., lb/M ft²	Caliper, pt	Bursting Strength, psig	Flat Crush, psi	Edgewise Compression, lb/in.: MD	Edgewise Compression, lb/in.: CD	Flexural Stiffness, lb-in.: MD (D_x)	Flexural Stiffness, lb-in.: CD (D_y)	Flexural Stiffness, lb-in.: $\sqrt{D_x D_y}$	Pin Adhesion, lb[a]
						C-flute Constructions							
1	26	26.2	67	93	149	184	39.2	12.2	34.3	80.2	38.8	55.8	42
2	26	23.3	54	91	145	180	42.2	13.2	37.1	74.6	35.6	51.5	38
4	26	21.7	44	88	140	184	22.6	10.8	31.8	83.0	34.6	53.6	35
3	26	20.0	41	84	134	188	24.2	10.8	31.2	78.9	34.0	51.8	36
8	42	26.2	67	127	156	320	40.7	24.8	51.3	156.2	60.3	97.0	56
7	42	23.3	54	123	154	340	42.2	27.2	51.6	163.8	55.8	95.6	54
5	42	21.7	44	121	150	310	27.8	21.8	46.8	149.2	53.7	89.5	52
6	42	20.0	41	118	146	312	21.8	22.8	45.5	156.2	53.4	91.4	44
9	90	26.2	67	224	178	513	42.2	85.8	92.6	307.5	153.2	217.0	78
10	90	23.3	54	220	176	510	42.2	88.5	93.9	273.3	140.4	195.8	70
12	90	21.7	44	218	171	506	23.7	77.0	82.1	274.3	142.8	198.0	69
11	90	20.0	41	214	164	490	24.3	81.8	83.6	213.8	124.8	163.2	68
						B-flute Constructions							
13	42	26.2	67	122	117	323	46.5	39.5	51.4	85.0	30.1	50.6	68
14	42	23.3	54	118	116	312	44.4	38.5	53.6	85.1	30.6	51.0	70
16	42	21.7	44	118	116	316	30.8	37.0	48.8	86.8	31.0	51.8	67
15	42	20.0	41	114	112	308	31.7	36.0	47.6	81.0	27.8	47.4	88

[a]Test areas were 4.3 and 5.4 sq inch for C and B-flute boards, respectively.

TABLE IX

EFFECT OF MEDIUM WEIGHT ON COMBINED BOARD BURSTING STRENGTH

Run	Medium Characteristics: Basis Wt., lb/M ft^2	Medium Characteristics: Concora, lb	Bursting Strength, psig	Diff., %[a]
		C-flute — 26-lb Liners		
1	26.2	67	184	--
2	23.3	54	180	-2.2
4	21.7	44	184	0.0
3	20.0	41	188	+4.3
		C-flute — 42-lb Liners		
8	26.2	67	320	--
7	23.3	54	340	+6.2[b]
5	21.7	44	310	-3.1
6	20.0	41	312	-2.5
		C-flute — 90-lb Liners		
9	26.2	67	513	--
10	23.3	54	510	-0.6
12	21.7	44	506	-1.4
11	20.0	41	490	-4.5[b]
		B-flute — 42-lb Liners		
13	26.2	67	323	--
14	23.3	54	312	-3.4
16	21.7	44	316	-2.2
15	20.0	41	308	-4.6
		Composite		
--	26.2	67	335	--
--	23.3	54	336	+0.3
--	21.7	44	329	-1.8
--	20.0	41	324	-3.3[b]

[a]Based on results for constructions made with 26-lb mediums as reference.

[b]Significant at the 0.05 level.

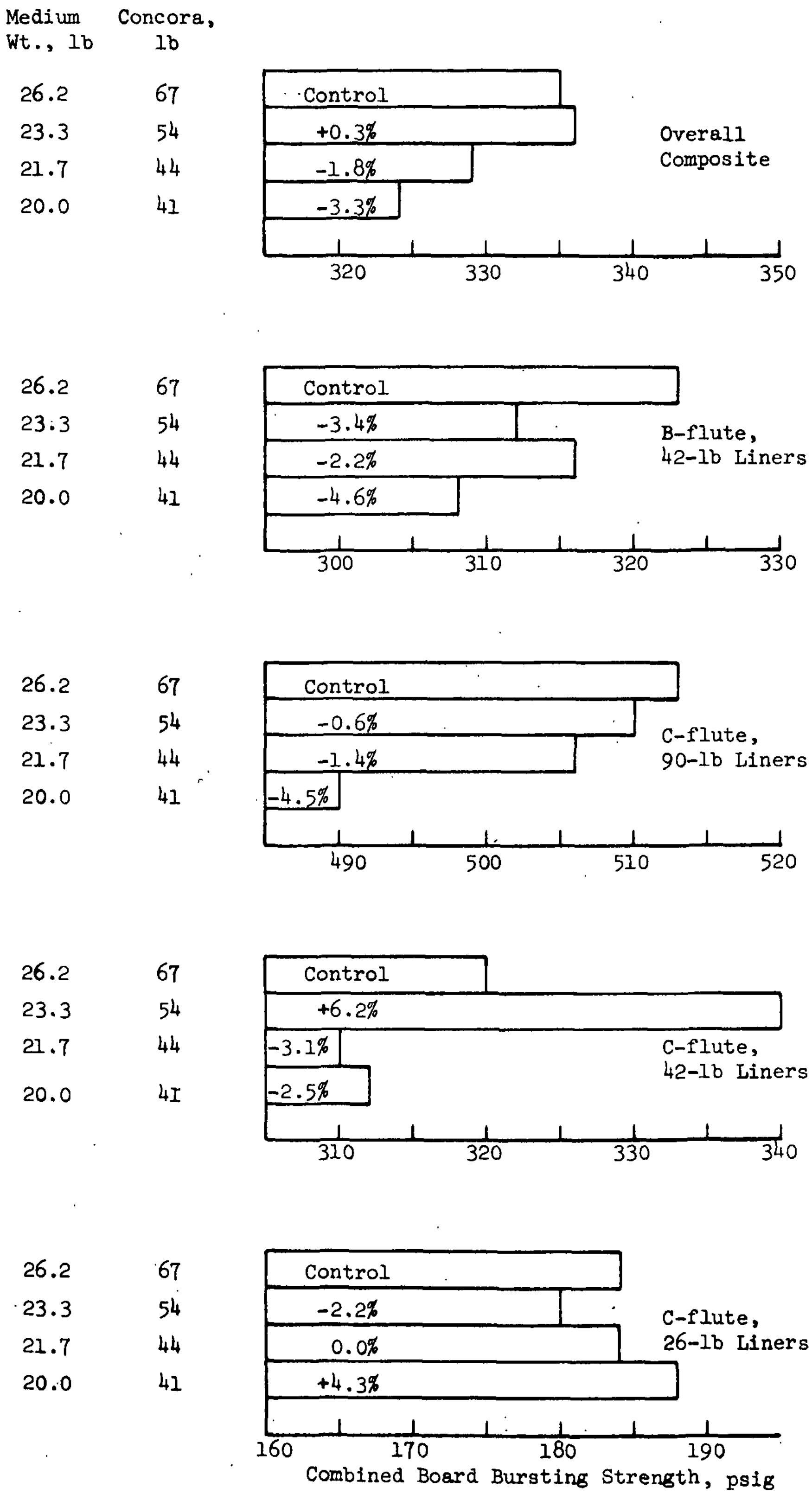

Figure 8. Comparison of Combined Bursting Strength Results for the Composite of Samples Taken from the No. 2-1/2 Can Size and 22 x 16 x 18-Inch Boxes

on the bursting strength of the liners. As one consequence, the combined board bursting strength results fail to predict the effect of medium weight on either box compression or box corner drop which were discussed in the previous section.

The flat crush results are tabulated in Table X, and illustrated in Fig. 9. Despite the lower Concora strength of the 23-lb medium, the combined board flat crush values for the constructions made with 23-lb medium were approximately the same as those exhibited by the 26-lb medium constructions. The percentage differences were +7.6, +3.7 and 0.0% for the C-flute boards, -4.5% for the B-flute boards and +1.4% in the overall composite. While these differences were statistically significant in three of the five comparisons, the differences were both positive and negative. Thus it may be possible to reduce medium basis weight to about 23 lb without affecting flat crush strength to any great extent providing appropriate medium flat crush levels are maintained.

The 20- and 22-lb mediums having Concora levels of 41 and 44 lb, respectively, exhibited relatively low flat crush values compared to the 26-lb mediums. The composite average reductions in flat crush strength for the 20- and 22-lb mediums were -39.6 and -37.9%, respectively, and both reductions were highly significant.

Table XI compares the effect of medium weight on combined board edgewise compression strength. As discussed in Ref. (2), the cross-direction edgewise compression strength and flexural stiffnesses of the combined board are the properties which govern top-load box compression strength. Changes in the cross-direction edgewise compression strength have a much greater effect on top-load box compression than corresponding changes in flexural stiffness. Therefore, referring to the table or to Fig. 10, it may be noted that the constructions made with 23-lb medium tended to give about equal or slightly higher CD edgewise strength than the constructions

TABLE X

COMBINED BOARD FLAT CRUSH RESULTS

Run	Medium Characteristics: Basis Wt., lb/M ft^2	Medium Characteristics: Concora, lb	Flat Crush, psi	Diff., %[a]
		C-flute — 26-lb Liners		
1	26.2	67	39.2	--
2	23.3	54	42.2	+7.6[b]
4	21.7	44	22.6	-42.3[b]
3	20.0	41	24.2	-38.3[b]
		C-flute — 42-lb Liners		
8	26.2	67	40.7	--
7	23.3	54	42.2	+3.7[b]
5	21.7	44	27.8	-31.7[b]
6	20.0	41	21.8	-46.4[b]
		C-flute — 90-lb Liners		
9	26.2	67	42.2	--
10	23.3	54	42.2	0.0
12	21.7	44	23.7	-43.8[b]
11	20.0	41	24.3	-42.4[b]
		B-flute — 42-lb Liners		
13	26.2	67	46.5	--
14	23.3	54	44.4	-4.5[b]
16	21.7	44	30.8	-33.8[b]
15	20.0	41	31.7	-31.8[b]
		Composite		
--	26.2	67	42.2	--
--	23.3	54	42.8	+1.4
--	21.7	44	26.2	-37.9[b]
--	20.0	41	25.5	-39.6[b]

[a] Based on results for constructions made with 26-lb medium as reference.

[b] Significant at the 0.05 level.

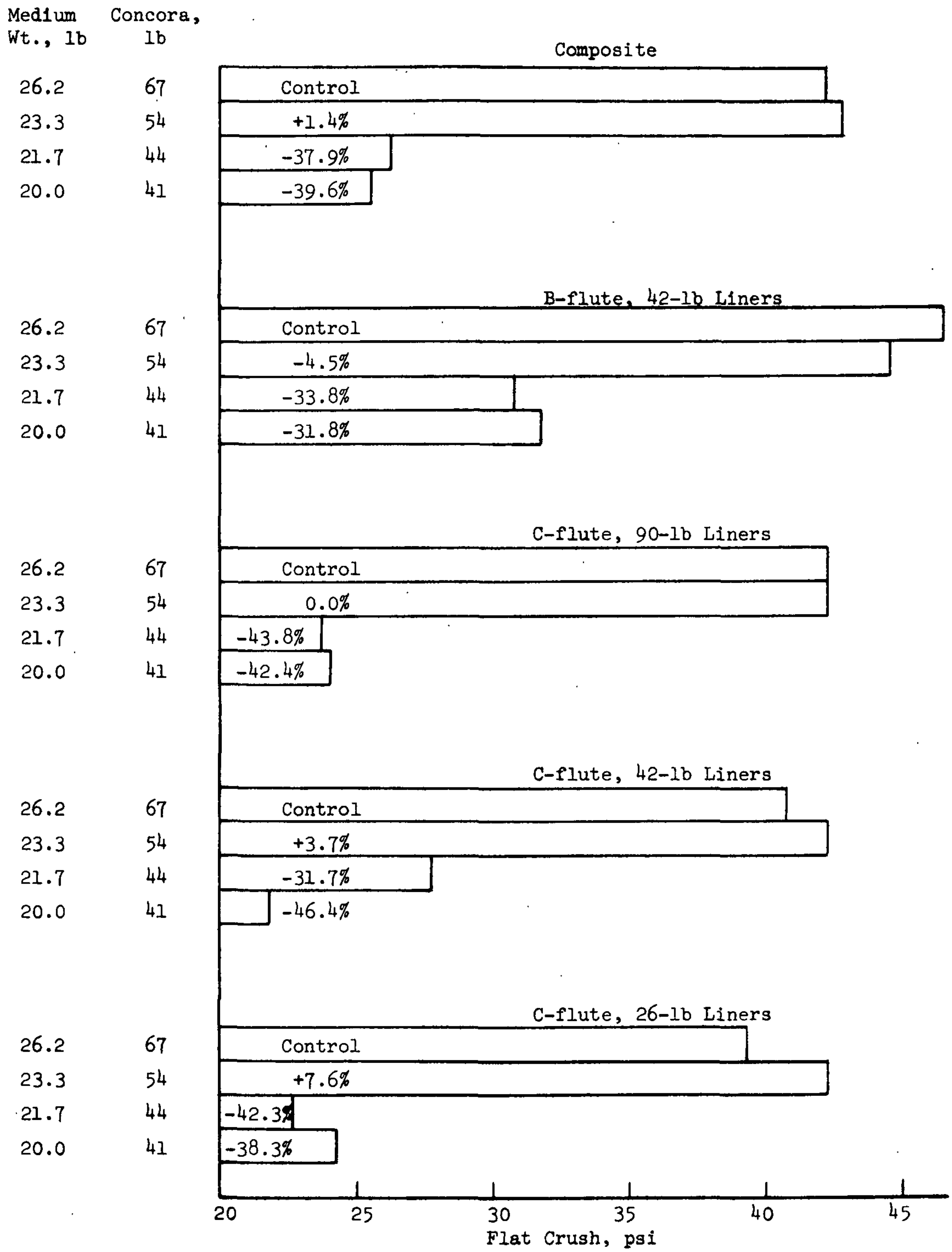

Figure 9. Effect of Medium Weight and Concora on Combined Board Flat Crush

TABLE XI

EFFECT OF MEDIUM WEIGHT ON COMBINED BOARD
EDGEWISE COMPRESSION STRENGTH

	Medium Characteristics		Edgewise Compression, lb/inch			
Run	Basis Wt., lb/M ft^2	Concora, lb	MD	Diff., %[a]	CD	Diff., %[a]
			C-flute — 26-lb Liners			
1	26.2	67	12.2	--	34.3	--
2	23.3	54	13.2	+8.2	37.1	+8.2[b]
4	21.7	44	10.8	-11.5	31.8	-7.3[b]
3	20.0	41	10.8	-11.5	31.2	-9.0[b]
			C-flute — 42-lb Liners			
8	26.2	67	24.8	--	51.3	--
7	23.3	54	27.2	+9.7	51.6	+0.6
5	21.7	44	21.8	-12.1	46.8	-8.8[b]
6	20.0	41	22.8	-8.1	45.5	-11.3[b]
			C-flute — 90-lb Liners			
9	26.2	67	85.8	--	92.6	--
10	23.3	54	88.5	+3.2	93.9	+1.4
12	21.7	44	77.0	-10.3	82.1	-11.3[b]
11	20.0	41	81.8	-4.7	83.6	-9.7[b]
			B-flute — 42-lb Liners			
13	26.2	67	39.5	--	51.4	--
14	23.3	54	38.5	-2.5	53.6	+4.3[b]
16	21.7	44	37.0	-6.3	48.8	-5.1[b]
15	20.0	41	36.0	-8.9	47.6	-7.4[b]
			Composite			
--	26.2	67	40.6	--	57.4	--
--	23.3	54	41.8	+3.0	59.0	+2.8[b]
--	21.7	44	36.6	-9.8	52.4	-8.7[b]
--	20.0	41	37.8	-6.9	52.0	-9.4[b]

[a]Based on results for constructions made with 26-lb medium as reference.

[b]Significant at the 0.05 level. The significance tests were made on the cross-direction results only.

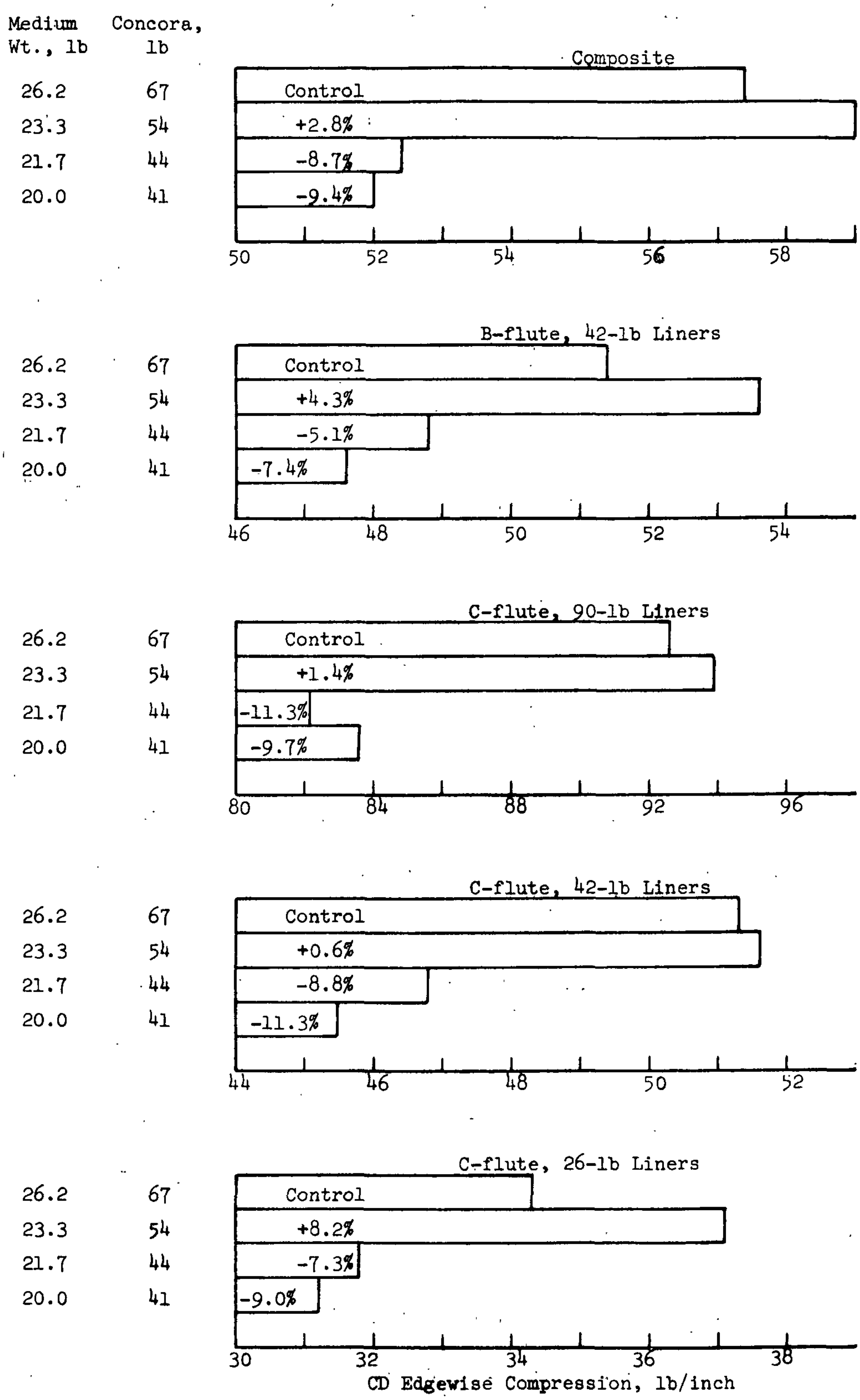

Figure 10. Effect of Medium Weight on the Cross-Direction Combined Board Edgewise Compression Strength

made with 26-lb medium. The differences in strength between the 23- and 26-lb constructions were statistically significant in only two of the four cases. While the overall difference of +2.8% was statistically significant it is not considered to be of practical importance.

The equal or slightly higher combined board CD edgewise compression strengths obtained with the 23-lb medium are due to the fact that the cross direction edgewise compression strength of the 23-lb medium was slightly higher than the CD strength of the 26-lb medium as shown below:

Run	Medium Wt., lb/M ft^2	Cross-Direction Modified Ring Compression, lb/inch
1, 8, 9, 13	26.2	10.9
2, 7, 10, 14	23.3	11.6
4, 5, 12, 16	21.7	7.3
3, 6, 11, 15	20.0	7.6

It also may be recalled that the top-load box compression results for the boxes made with 23-lb medium were about equal to those obtained with 26-lb medium. Thus it appears that the cross-direction edgewise compression strength and top-load box compression trends are in reasonable agreement.

The cross-direction edgewise compression strengths of the combined boards made with 20- and 22-lb mediums were significantly lower than the results obtained with 26-lb medium. This would be expected in view of their lower cross direction modified ring compression strengths.

The machine-direction edgewise compression strength of combined board is one of the major properties employed in past work to predict end-load compression (3,4). However, the formulas developed had relatively high predictive error. With this in mind, it may be noted the 23-lb medium combined boards exhibited MD compressive strengths ranging from -2.5 to +9.7% depending on the flute and liners employed. The boards made with the 20- and 22-lb mediums exhibited lower MD edgewise compression strengths than the 26-lb boards in all cases. In general, it appears that the magnitudes of the changes in MD edgewise compression strength with varying medium weights are less than were obtained in end-load box compression, thus suggesting that an improved or different method of evaluating MD compression strength is needed.

The combined board flexural stiffness results are summarized in Table XII and illustrated in Fig. 11 and 12 for the machine and cross-machine directions, respectively. The geometric means of the machine and cross-machine direction flexural stiffness results are illustrated in Fig. 13. It may be recalled that top-load box compression is dependent, in part, on the flexural stiffnesses of the combined board and, specifically, on the geometric mean ($\sqrt{D_x D_y}$) of the flexural stiffnesses in the two directions. However, as discussed in Ref. (2,5) the exponent on the factor $\sqrt{D_x D_y}$ in the box formula is only about 0.25 whereas the exponent on the edgewise compression strength is about 0.75. Thus, top-load box compression strength is much less sensitive to changes in flexural stiffness as compared to edgewise compression strength.

As noted in Ref. (2), the flexural stiffness of corrugated board is primarily dependent on the moduli of elasticity and caliper of the liners and the caliper of the combined board. In the case of cross direction flexural stiffness, there is also a small contribution from the modulus of elasticity of the medium and the moment of inertia of the flute.

With the above in mind, the machine direction flexural stiffness results in Table XII and Fig. 11 show that medium weight generally did not have any major and consistent effect on stiffness except for the constructions with 90-lb liners.

TABLE XII

COMBINED BOARD FLEXURAL STIFFNESS RESULTS

Run	Medium Characteristics: Basis Wt., lb/M ft²	Medium Characteristics: Concora, lb	Flexural Stiffness, lb-inch: MD (D_x)	Diff., %[a]	CD (D_y)	Diff., %[a]	$\sqrt{D_x D_y}$	Diff., %[a]
			C-flute — 26-lb Liners					
1	26.2	67	80.2	--	38.8	--	55.8	--
2	23.3	54	74.6	-7.0[b]	35.6	-8.2[b]	51.5	-7.7
4	21.7	44	83.0	+3.5	34.6	-10.8[b]	53.6	-3.6
3	20.0	41	78.9	-1.6	34.0	-12.4[b]	51.8	-7.2
			C-flute — 42-lb Liners					
8	26.2	67	156.2	--	60.3	--	97.0	--
7	23.3	54	163.8	+4.9[b]	55.8	-7.5[b]	95.6	-1.4
5	21.7	44	149.2	-4.5[b]	53.7	-10.9[b]	89.5	-7.7
6	20.0	41	156.2	0.0	53.4	-11.4[b]	91.4	-5.8
			C-flute — 90-lb Liners					
9	26.2	67	307.5	--	153.2	--	217.0	--
10	23.3	54	273.3	-11.1[b]	140.4	-8.4[b]	195.8	-9.8
12	21.7	44	274.3	-10.8[b]	142.8	-6.8[b]	198.0	-8.8
11	20.0	41	273.3	-30.5[b]	124.8	-18.5[b]	163.2	-24.8
			B-flute — 42-lb Liners					
13	26.2	67	85.0	--	30.1	--	50.6	--
14	23.3	54	85.1	+0.1	30.6	+1.7	51.0	+0.8
16	21.7	44	86.8	+2.1	31.0	+3.0[b]	51.8	+2.4
15	20.0	41	81.0	-4.7[b]	27.8	-7.6[b]	47.4	-6.3
			Composite					
--	26.2	67	157.2	--	70.6	--	105.1	--
--	23.3	54	149.2	-5.1[b]	65.6	-7.1[b]	98.5	-6.3
--	21.7	44	148.3	-5.7	65.6	-7.1[b]	98.2	-6.6
--	20.0	41	132.5	-15.7[b]	60.0	-15.0[b]	88.4	-15.9

[a]Based on 26-lb medium constructions as reference.

[b]Significant at the 0.05 level. The significance tests were carried out on both the MD and CD results but not on the geometric mean ($\sqrt{D_x D_y}$).

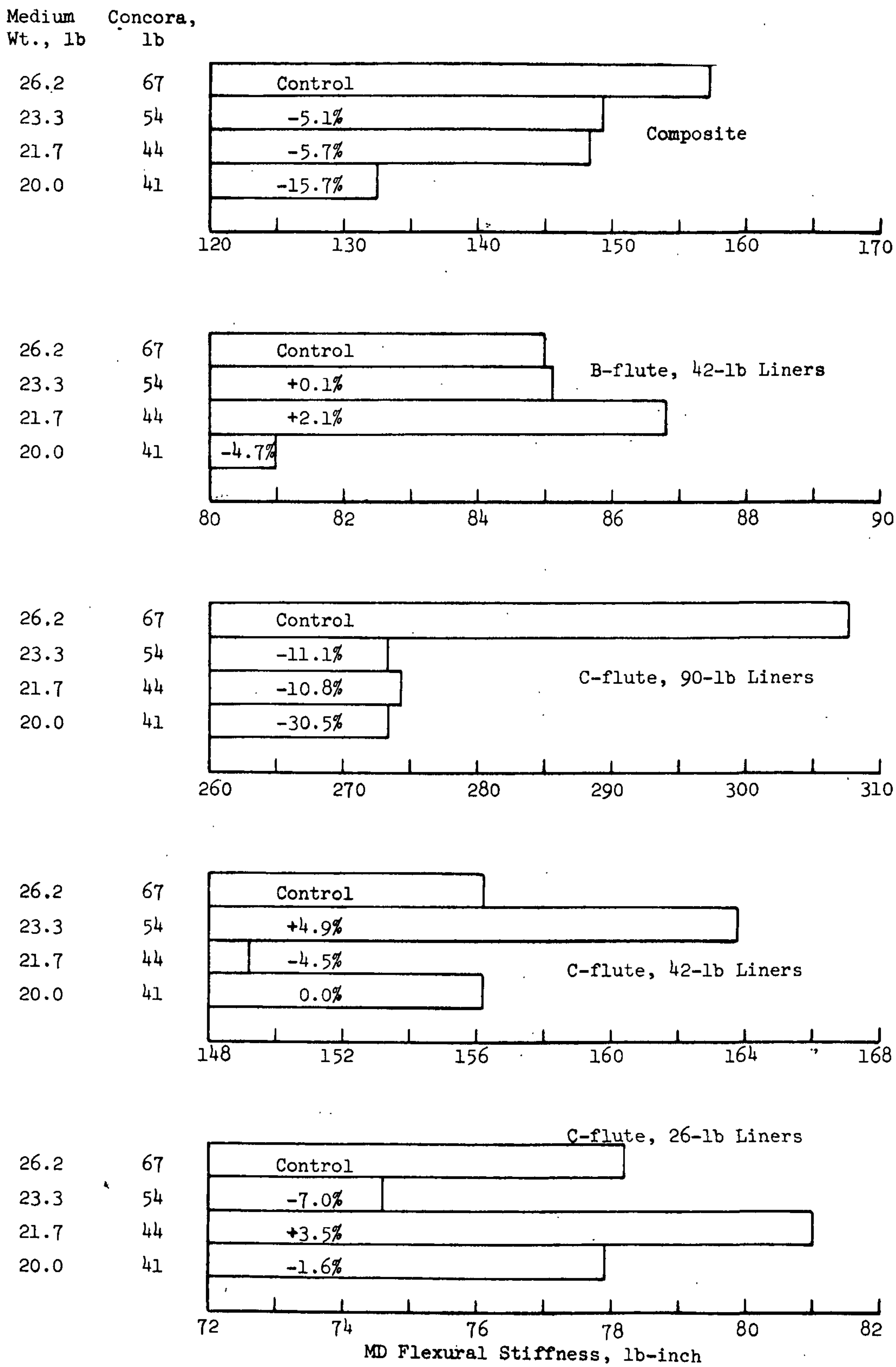

Figure 11. Effect of Medium Weight on the Machine Direction Flexural Stiffness of Combined Board

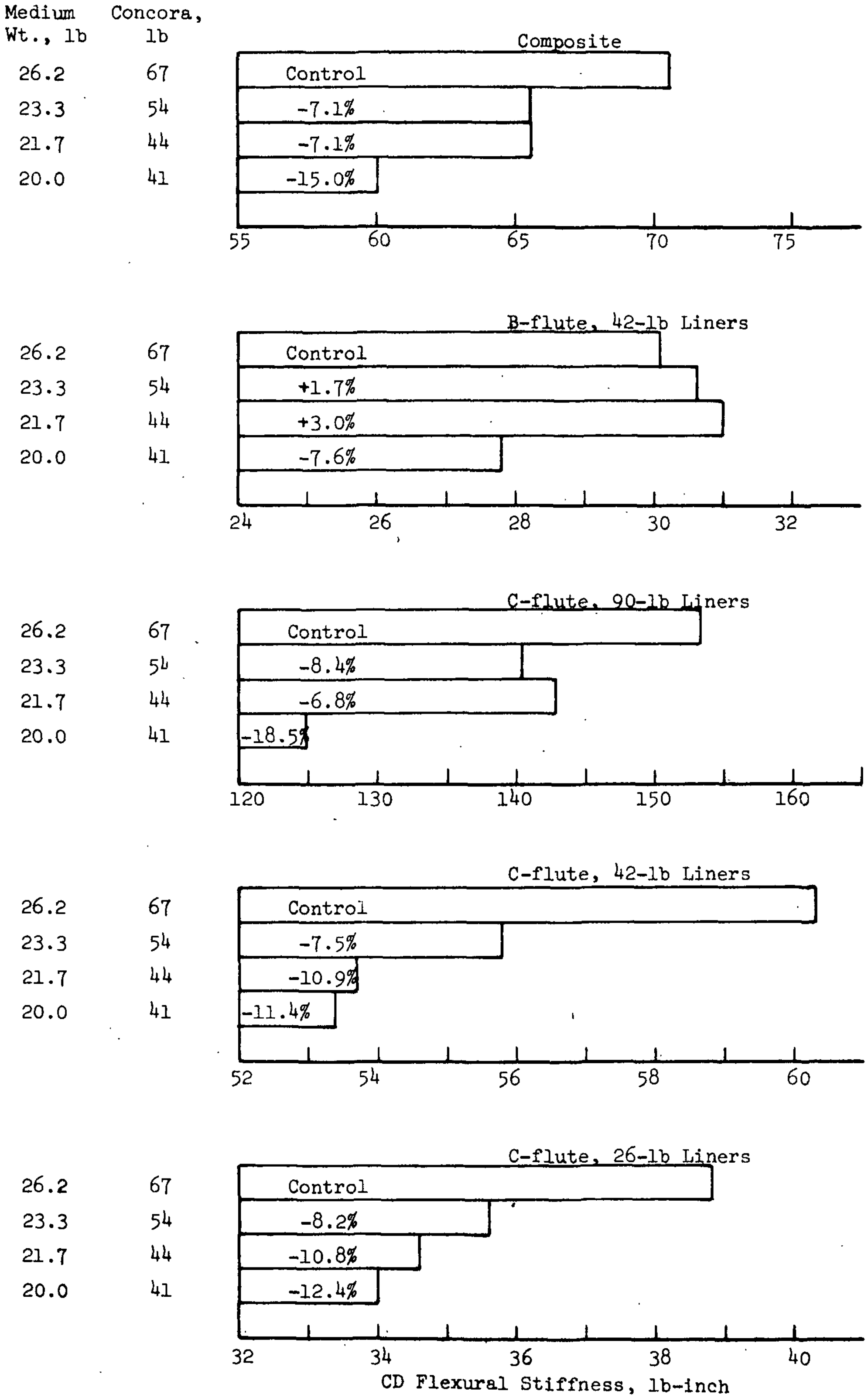

Figure 12. Effect of Medium Weight on the Cross-Direction Flexural Stiffness of Combined Board

In the latter case the 20-, 22- and 23-lb medium constructions exhibited significant reductions in MD stiffness of -30.5, -10.8 and -11.1%.

As would be expected from the previous discussion, decreasing the medium weight generally lowered the cross-direction flexural stiffnesses as shown in Fig. 12. However, on an overall basis, the reduction in CD flexural stiffness in going from 26- to 23-lb medium was only 7.1%. A reduction of this magnitude would be expected to have a considerably smaller percentage effect on box compression strength.

The geometric means of the flexural stiffnesses in the two directions are shown in Fig. 13. In general, the reductions in medium weight from 26 to 23 lb resulted in relatively small decreases in $\sqrt{D_x D_y}$ in most cases. On an overall basis the reduction in $\sqrt{D_x D_y}$ associated with a change in medium weight from 26 to 23 lb was -6.3%. A change of this magnitude would be expected to decrease top-load box compression by only about 2%.

The combined board caliper results in Table XIII indicate that the caliper decreased progressively as the medium weight was lowered — averaging -1.3, -4.0 and -7.3% for the 23-, 22- and 20-lb mediums, respectively.

COMPONENT TEST RESULTS

The properties of the four corrugating mediums supplied for the study are shown in Table XIV. In addition to its lower Concora strength, the 23-lb medium exhibited lower caliper and markedly lower tearing strength than the 26-lb medium. The difference in tearing strength had a marked effect on the box corner drop results as previously discussed. In contrast, the 23-lb medium exhibited slightly higher CD ring compression and its MD ring compression was about the same as obtained with the 26-lb medium. The 22- and 20-lb mediums exhibited markedly lower caliper, Concora and ring compression strengths as would be expected.

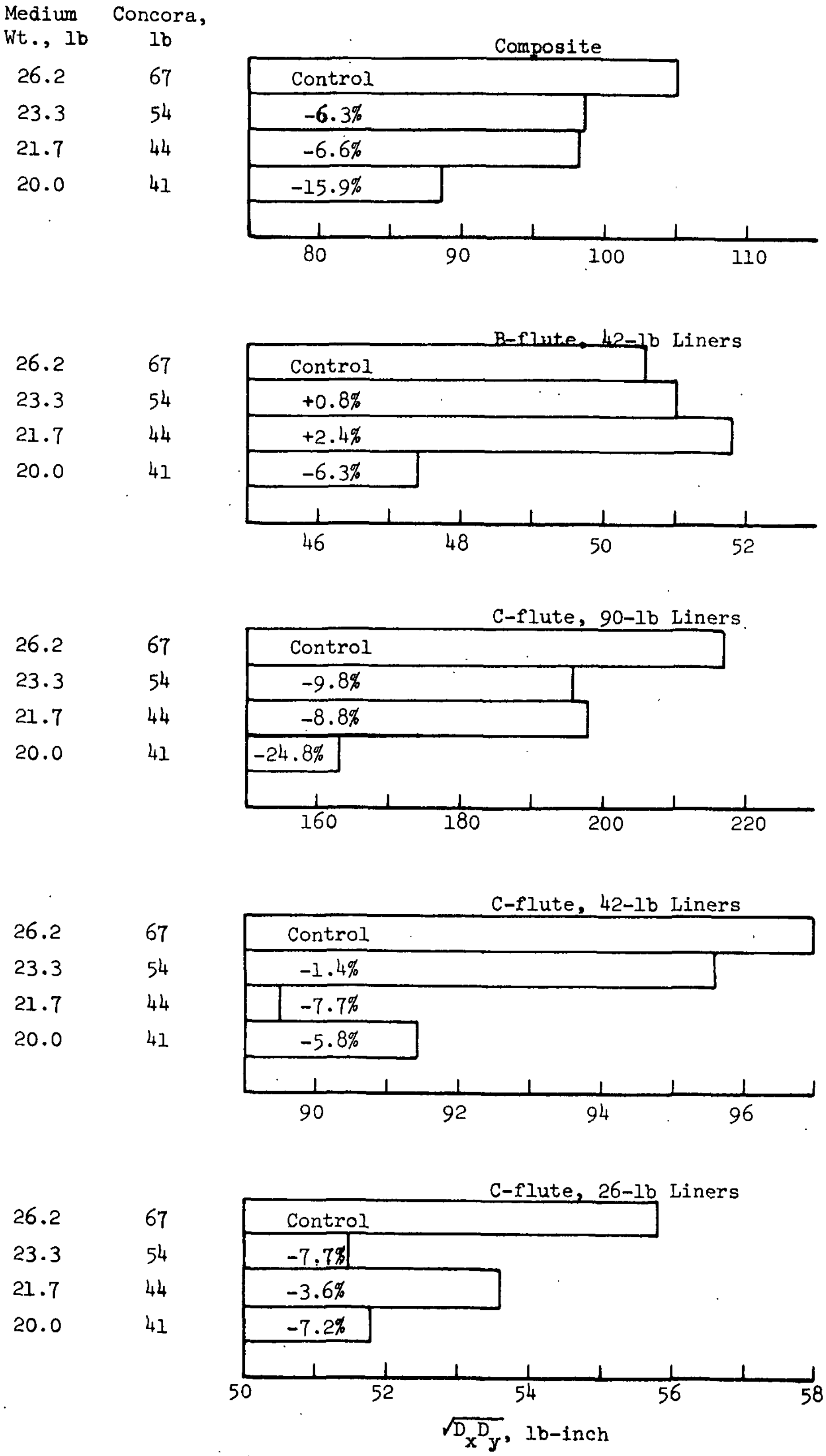

Figure 13. Effect of Medium Weight on the Geometric Mean ($\sqrt{D_x D_y}$) of the Machine and Cross-Direction Flexural Stiffnesses of Combined Board

TABLE XIII

COMBINED BOARD CALIPER RESULTS

Run	Medium Characteristics: Basis Wt., lb/M ft^2	Medium Characteristics: Concora, lb	Caliper, pt	Diff., %[a]
		C-flute — 26-lb Liners		
1	26.2	67	149	--
2	23.3	54	145	-2.7
4	21.7	44	140	-6.0
3	20.0	41	134	-10.1
		C-flute — 42-lb Liners		
8	26.2	67	156	--
7	23.3	54	154	-1.3
5	21.7	44	150	-3.8
6	20.0	41	146	-6.4
		C-flute — 90-lb Liners		
9	26.2	67	178	--
10	23.3	54	176	-1.1
12	21.7	44	171	-3.9
11	20.0	41	164	-7.9
		B-flute — 42-lb Liners		
13	26.2	67	117	--
14	23.3	54	116	-0.9
16	21.7	44	116	-0.9
15	20.0	41	112	-4.3
		Composite		
--	26.2	67	150	--
--	23.3	54	148	-1.3
--	21.7	44	144	-4.0
--	20.0	41	139	-7.3

[a]Based on 26-lb medium constructions as reference.

However, as mentioned previously, the tearing strength of the 21.7-lb medium was about the same as that of the 26-lb medium.

TABLE XIV

MEDIUM CHARACTERISTICS

Run	Basis Wt., lb/M ft^2	Caliper, pt	Concora, lb	Mod. Ring Compression, lb/inch		Elmendorf, Tear, g	
				MD	CD	MD	CD
1, 8, 9, 13	26.2	10.0	67	16.0	10.9	98	128
2, 7, 10, 14	23.3	9.0	54	15.9	11.6	53	62
4, 5, 12, 16	21.7	8.0	44	11.8	7.3	99	125
3, 6, 11, 15	20.0	8.0	41	10.8	7.6	58	70

The properties of the 26-, 42- and 90-lb linerboards used in the study are shown in Table XV.

TABLE XV

LINERBOARD CHARACTERISTICS

Run	Basis Wt., lb/M ft^2	Caliper, pt	Bursting Strength, psig	Mod. Ring Compression, lb/inch		Tearing Strength, g	
				MD	CD	MD	CD
1-4	26.4	8.1	83	16.9	12.4	175	230
5-8, 13-16	42.7	11.2	123	20.8	17.3	280	364
9-12	91.7	22.8	214	44.0	38.2	697	930

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APPENDIX I

BOX DEFLECTION RESULTS

TABLE XVI

TOP LOAD BOX DEFLECTION RESULTS

	Medium Characteristics		Deflection at Maximum Load, inch.					
Run	Basis Wt., lb/M ft^2	Concora, lb	No. 2-1/2 Can Box	Diff., %	22x16x18 Inch Box	Diff., %	Composite	Diff., %
			C-flute — 26-lb Liners					
1	26.2	67	0.39	--	0.47	--	0.43	--
2	23.3	54	0.39	0.0	0.45	-4.3	0.42	-2.3
4	21.7	44	0.33	-15.4	0.42	-10.6	0.38	-11.6
3	20.0	41	0.34	-12.4	0.41	-12.8	0.38	-11.6
			C-flute — 42-lb Liners					
8	26.2	67	0.45	--	0.50	--	0.48	--
7	23.3	54	0.43	-4.4	0.47	-6.0	0.45	-6.2
5	21.7	44	0.42	-6.7	0.45	-10.0	0.44	-8.3
6	20.0	41	0.40	-11.1	0.43	-14.0	0.42	-12.5
			C-flute — 90-lb Liners					
9	26.2	67	0.61	--	0.56	--	0.58	--
10	23.3	54	0.63	+3.3	0.56	0.0	0.60	+3.4
12	21.7	44	0.84	+37.7	0.50	-10.7	0.67	+15.5
11	20.0	41	0.70	+14.8	0.53	-5.4	0.62	+6.9
			B-flute — 42-lb Liners					
13	26.2	67	0.35	--	0.40	--	0.38	--
14	23.3	54	0.36	+2.9	0.38	-5.0	0.37	-2.6
16	21.7	44	0.40	+14.3	0.34	-15.0	0.37	-2.6
15	20.0	41	0.30	-14.3	0.36	-10.0	0.33	-13.2
			Composite					
--	26.2	67	0.45	--	0.48	--	0.47	--
--	23.3	54	0.45	0.0	0.46	-4.2	0.46	-2.1
--	21.7	44	0.50	+11.1	0.43	-10.4	0.46	-2.1
--	20.0	41	0.44	-2.2	0.43	-10.4	0.44	-6.4

TABLE XVII

END LOAD BOX DEFLECTION RESULTS

	Medium Characteristics		Deflection at Maximum Load, inch					
Run	Basis Wt., lb/M ft^2	Concora, lb	No. 2-1/2 Can Box	Diff., %	22x16x18 Inch Box	Diff., %	Composite	Diff., %
			C-flute — 26-lb Liners					
1	26.2	67	0.15	--	0.23	--	0.19	--
2	23.3	54	0.17	+13.3	0.21	-8.7	0.19	0.0
4	21.7	44	0.18	+20.0	0.29	+26.1	0.24	+26.3
3	20.0	41	0.16	+6.7	0.28	+21.7	0.22	+15.8
			C-flute — 42-lb Liners					
8	26.2	67	0.28	--	0.33	--	0.30	--
7	23.3	54	0.25	-10.7	0.34	+3.0	0.30	0.0
5	21.7	44	0.28	0.0	0.32	-3.0	0.30	0.0
6	20.0	41	0.25	-10.7	0.35	+6.1	0.30	0.0
			C-flute — 90-lb Liners					
9	26.2	67	0.37	--	0.39	--	0.38	--
10	23.3	54	0.34	-8.1	0.36	-7.7	0.35	-7.9
12	21.7	44	0.34	-8.1	0.38	-2.6	0.36	-5.3
11	20.0	41	0.30	-18.9	0.35	-10.3	0.32	-15.8
			B-flute — 42-lb Liners					
13	26.2	67	0.28	--	0.30	--	0.29	--
14	23.3	54	0.25	-10.7	0.30	0.0	0.28	-3.4
16	21.7	44	0.33	+17.9	0.37	+23.3	0.35	+20.7
15	20.0	41	0.29	+3.6	0.34	+13.3	0.32	+10.3
			Composite					
--	26.2	67	0.27	--	0.31	--	0.29	--
--	23.3	54	0.25	-7.4	0.30	-3.2	0.28	-3.4
--	21.7	44	0.28	+3.7	0.34	+9.7	0.31	+6.9
--	20.0	41	0.25	-7.4	0.33	+6.4	0.29	0.0

APPENDIX II

COMBINED BOARD TEST RESULTS

TABLE XVIII

C-FLUTE COMBINED BOARD CHARACTERISTICS

Run	Nominal Liner Wt., lb/M ft²	Medium Characteristics: Basis Wt., lb/M ft²	Medium Characteristics: Concora, lb	Box Size[a]	Basis Wt., lb/M ft²	Caliper, pt	Bursting Strength, psig	Flat Crush, psi	Edgewise Compression, lb/inch: MD	Edgewise Compression, lb/inch: CD	Flexural Stiffness, lb-inch: MD (D_x)	Flexural Stiffness, lb-inch: CD (D_y)	Flexural Stiffness, lb-inch: $\sqrt{D_x D_y}$	Pin Adhesion,[b] lb
1	26	26.2	67	Small	93	149	186	38.7	12.0	34.8	79.3	38.4	55.2	38
				Large	93	149	183	39.7	12.5	33.8	81.1	39.1	56.3	46
				Av.	93	149	184	39.2	12.2	34.3	80.2	38.8	55.8	42
2	26	23.3	54	Small	92	145	184	42.9	13.0	36.3	70.9	34.9	49.7	35
				Large	90	145	177	41.4	13.5	37.9	78.3	36.3	53.3	42
				Av.	91	145	180	42.2	13.2	37.1	74.6	35.6	51.5	38
4	26	21.7	44	Small	89	139	186	22.1	10.5	32.1	78.3	33.7	51.4	32
				Large	88	140	182	23.2	11.0	31.4	87.8	35.6	55.9	38
				Av.	88	140	184	22.6	10.8	31.8	83.0	34.6	53.6	35
3	26	20.0	41	Small	84	133	188	20.0[c]	10.5	31.8	73.0	32.0	48.3	36
				Large	84	134	189	28.5[c]	11.0	30.5	84.8	36.0	55.2	35
				Av.	84	134	188	24.2	10.8	31.2	78.9	34.0	51.8	36
8	42	26.2	67	Small	128	156	328	41.5	24.0	51.8	152.9	62.2	97.5	47
				Large	126	155	312	39.9	25.5	50.8	159.6	58.4	96.5	66
				Av.	127	156	320	40.7	24.8	51.3	156.2	60.3	97.0	56
7	42	23.3	54	Small	124	154	343	42.7	28.0	52.3	154.6	52.7	90.2	51
				Large	122	154	337	41.8	26.5	50.8	172.9	58.9	100.9	56
				Av.	123	154	340	42.2	27.2	51.6	163.8	55.8	95.6	54
5	42	21.7	44	Small	122	150	314	27.8	21.0	47.3	144.9	51.1	86.1	50
				Large	120	149	307	27.9	22.5	46.2	153.4	56.3	92.9	54
				Av.	121	150	310	27.8	21.8	46.8	149.2	53.7	89.5	52
6	42	20.0	41	Small	118	146	314	22.3	22.0	45.6	146.8	50.0	85.8	32
				Large	118	147	311	21.4	23.5	45.4	165.5	56.8	96.9	56
				Av.	118	146	312	21.8	22.8	45.5	156.2	53.4	91.4	44
9	90	26.2	67	Small	225	178	508	43.1	85.0	91.6	309.5	157.0	220.4	77
				Large	223	178	518	41.2	86.5	93.5	305.5	149.5	213.7	80
				Av.	224	178	513	42.2	85.8	92.6	307.5	153.2	217.0	78
10	90	23.3	54	Small	220	175	510	43.4	89.0	94.4	285.0[c]	136.1	196.9	65
				Large	219	176	510	41.1	88.0	93.4	261.6[c]	144.7	194.6	74
				Av.	220	176	510	42.2	88.5	93.9	273.3	140.4	195.8	70
12	90	21.7	44	Small	217	170	506	25.4	75.5	80.7	268.4	142.6	195.6	66
				Large	219	172	505	22.0	78.5	83.5	280.2	143.1	200.3	72
				Av.	218	171	506	23.7	77.0	82.1	274.3	142.8	198.0	69
11	90	20.0	41	Small	214	163	487	24.9	83.5	81.9	198.7	106.7[c]	145.6	64
				Large	215	165	492	23.7	80.0	85.2	229.0	142.8	180.8	71
				Av.	214	164	490	24.3	81.8	83.6	213.8	124.8	163.2	68

[a] Small box = No. 2-1/2 can size, large box = 22x16x18 inches.
[b] Test area = 4.3 sq inch.
[c] Specimens exhibited leaning flutes and low caliper.

TABLE XIX

B-FLUTE COMBINED BOARD CHARACTERISTICS

Run	Nominal Liner Wt., lb/M ft^2	Medium Characteristics Basis Wt., lb/M ft^2	Medium Characteristics Concora, lb	Box Size[a]	Basis Wt., lb/M ft^2	Caliper, pt	Bursting Strength, psig	Flat Crush, psi	Edgewise Compression, lb/inch MD	Edgewise Compression, lb/inch CD	Flexural Stiffness, lb-inch MD (D_x)	Flexural Stiffness, lb-inch CD (D_y)	Flexural Stiffness, lb-inch $\sqrt{D_x D_y}$	Pin Adhesion,[b] lb
13	42	26.2	67	Small	124	117	322	46.0	41.0	51.6	84.4	30.3	50.5	74
				Large	121	117	324	47.0	38.0	51.2	85.6	29.9	50.6	62
				Av.	122	117	323	46.5	39.5	51.4	85.0	30.1	50.6	68
14	42	23.3	54	Small	119	116	309	43.5	39.0	53.6	85.2	32.0	52.2	65
				Large	118	117	314	45.3	38.0	53.6	85.0	29.3	49.9	74
				Av.	118	116	312	44.4	38.5	53.6	85.1	30.6	51.0	70
16	42	21.7	44	Small	118	116	314	30.7	37.0	49.0	82.9	32.4	51.8	67
				Large	117	117	318	30.8	37.0	48.6	90.6	29.5	51.7	67
				Av.	118	116	316	30.8	37.0	48.8	86.8	31.0	51.8	67
15	42	20.0	41	Small	114	110	308	31.3	36.0	48.7	77.3	27.2	45.8	96
				Large	114	114	307	32.1	36.0	46.4	84.8	28.3	49.0	80
				Av.	114	112	308	31.7	36.0	47.6	81.0	27.8	47.4	88

[a] Small box = No. 2-1/2 can size; large box = 22x16x18 inches.
[b] Test area = 5.4 sq. inch.